ALENTOS GIYA GUAHAN • ENERGY ON GUAM

economic and environmental impacts of low head hydroelectric power systems on Guam

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GUAM ENERGY OFFICE • GOVERNMENT OF GUAM
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ECONOMIC AND ENVIRONMENTAL IMPACTS OF LOW HEAD HYDROELECTRIC POWER SYSTEMS ON GUAM

for the

GUAM ENERGY OFFICE
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GOVERNMENT OF GUAM
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Agana, Guam
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

I. INTRODUCTION

A. PURPOSE OF STUDY

The purpose of this study is to address Guam's potential for hydroelectric development, and particularly the economic and environmental impacts of hydro generation facilities at existing and proposed water improvement structures associated with the main rivers of Southern Guam. The study will explore the potential of the proposed Ugum River Dam site, along with alternative sites, for hydroelectric developments in sizes ranging from 5 MW down to small farm or home use.

Information obtained from this study will assist the Guam Energy Office and the Bureau of Planning's Guam Coastal Management Program in further assessment of renewable, nonpolluting alternative energy resources. It will also be of value to the decision-making process regarding the location of proposed dam sites on Guam's rivers.

B. CENTRAL ENERGY IMPACT PROGRAM

In order to "provide grants and credit assistance to the Coastal states and communities to help them deal with the impacts of coastal energy development," the Coastal Energy Impact Program (CEIP) was created, on June 26, 1976.

Guam qualified for assistance in the program and was funded under section 308(c) of the Coastal Zone Management Act of which CEIP is a part. This study was funded for the purpose of "Studying the Consequences of Energy Facilities."

> Such grants shall be used for the study of, and planning for, any economic, social, or environmental consequences which has occurred, is occurring, or is likely to occur as a result of the siting, construction, expansion or operation of such new or expanded energy facilities. [Sec. 308(c) CZMA]

C. BACKGROUND

Historically, the U. S. has emphasized the development of large hydro sites, those over 15 MW. The smaller sites, lacking the advantage of benefits of economy of scale, and low long term operating costs, remained undeveloped.[1]

The current push toward alternate energy generation systems combined with problems associated with larger installations - high initial investments, legal environmental licensing impasses, lengthy planning, design and construction periods - has effected a renewed interest in smaller unit development.[2]

Hydro development is attractive for several reasons. It is a form of energy that is controlled easily, and is converted to work at an extremely high efficiency. Compared to solar, chemical and thermal efficiencies of 29 - 45%, hydro systems run 80 - 90% efficicient. If the source water is uncontaminated, it is pollution-free, does not produce waste residuals and consequently is an extremely "pure" form of energy. Because the work application can be readily matched to the potentials of the source, the complete range of available flow volumes can be used on Guam - from small streams to the largest rivers.[3]

Hydro generation is not "new" technology, but, rather, "proven" technology. Simply, the amount of energy available at a given location is a function of the quantity of water available, the vertical distance the water falls and the efficiency of the power plant.[4]

D. LIMITING FACTORS

The primary limiting factor on Guam for hydro development is the small flow volume of Guam's streams and rivers. Hydroelectric sites around the world are located on rivers many times larger than the largest river on Guam. For example, the Tucurui River in Brazil is presently being dammed for hydroelectric generation development. The plant is being designed to use a flow of 1.8 million cubic feet per second (CFS), and will have a capacity of 4,000 MW (Guam's peak demand is 150 MW).

By comparison, the largest average flow on Guam's rivers (the Talofofo River) about 50 CFS. This means that the largest hydro plant on Guam would still be a small installation by world-wide standards.

Contributing to the problem, storm activity and dry seasons effect radical changes in the flow of the waters on Guam, causing, alternately, flood and drought situations. This creates design and operation problems for hydro plants which utilize steady, year-round flows.

Although Guam's rivers have sections that fall several hundred vertical feet, these sections are generally the upper reaches of the rivers where the flow is small. In periods of heavy rains, waterfalls of limited flow volume are seen throughout the southern area of Guam. Some of these exceed 100 foot drops, but are of extremely limited duration, and/or are located in areas of limited access.

Access is a very important factor. Since the projected scale of local hydro development is small, the cost of civil works - roads, dams, piping - need to be minimized for a site to be cost effective. Since the cheapest access or maintenance roads currently cost approximately $25.00 per running foot (over $130,000.00 per mile), a prospective site would have to have an existing access road at, or nearby, the prospective site.

Another limiting factor for hydro design is local stream flow data. At this time, comprehensive flow data relative to hydro development is not available. Because of the great variability in natural stream flows, a hydrologic record that is as long as possible is needed in order to analyze any site's potential energy output. This record should include a representative sample of high-flow and low-flow years and should cover any critical dry period. For most cases, a period of 20 to 25 years is prefered. A shorter record, such as 8 to 10 years, is barely adequate, and on Guam is usually all that is available.

Locally, the major rivers and streams are guaged but at only one or two locations, usually near the estuary. Upstream data is scarce and neccessitate flow estimates which limit the accuracy of projected power potential.

E. LEGAL ISSUES

In addition to the above limiting factors, another potential roadblock to extensive hydroelectric development is the regulatory process. Although this is not a part of this study, it should be mentioned now and studied in depth in a subsequent study. There are numerous federal regulatory laws to which Stateside hydro projects must conform along with the various Federal, state, and local agencies that have to be contacted for licensing a hydro plant. Originally, statutes were designed to serve specific purposes, but have accumulated and combine to form an overlapping and conflicting authority over hydro development in the Mainland. The list is as follows:[5]

1. Federal Regulatory Acts Affecting Hydro Development:

   a. Federal Power Act

b. National Environmental Policy Act

c. Fish & Wildlife Coordination Act

d. Historical Preservation Act

e. Water Pollution Control Act

f. Wild & Scenic Rivers Act

g. Endangered Species Act

h. Federal Land Policy and Management Act

i. Water Quality Improvement Act

j. Coastal Zone Management Act

k. Public Utility Regulatory & Policies Act

l. National Wilderness Preservaton Act

2. Federal Agencies to Contact in FERC Prelicensing Process

a. U. S. Fish & Wildlife Service

b. Environmental Protection Agency

c. River Basin Commission

d. U. S. Army Corps of Engineers

e. National Marine Fisheries Service

f. Department of the Interior Environmental Division

g. Department of the Interior Heritage Conservation & Recreation Service

3. State Agencies - include those with responsibility for:

a. Dam Safety

b. Energy Development, Planning, and Research

c. Fish & Wildlife Preservation

d. Flood Control

e. Historical Preservation

f. Quality Control

g. Water Rights and Resources

h. In addtion, in some states the Public Utilities Commission must be contacted.

4. Local Agencies - include those with responsibility for:

a. Zoning

b. Property Acquisition

c. Taxation

At the end of 1980 the Federal Energy Regulatory Commission (FFRC) approved exemptions for small hydro projects - those which develop a generating capacity of less than 5 MW aggregate and use an existing dam or natural water feature, such as a diversion with no impoundment. Although this exemption gives preference to project owners where the project involves only non-Federal land, it also permits exemptions for projects located totally or partly on Federal soil. Another feature to the legislation is the automatic action clause, which mandates automatic action on exemption applications, 120 days after filing.[6]

F. STUDY GOALS

1. Describe the Study Area
2. Examine Five Possible Hydro Development Scenarios:

    a. Plant at existing impoundment areas
    b. Plant at proposed impoundment areas
    c. Plant at existing distribution system
    d. Plant at undeveloped site
    e. Small scale site development

3. Describe the Hyrological Characteristics of the Major Rivers, Streams, and Springs In the Study Area
4. Describe the Head and Power Potential of the Major Rivers, Streams, and Springs In the Study Area
5. Rank Existing and Prospective Sites as to Their Potential for Hydro Development
6. Produce Map of Major Rivers, Streams, and Springs, Using Color-Coding to Indicate Relative Average Annual Flow Volumes

G. STUDY METHODOLOGY

The first phase of this study was the collection and analysis of practical literature. Pursuant to this literature search, the author visited the local offices of the U. S.

Geological Survey, the U. S. Army Corps of Engineers, the Guam Environmental Protection Agency, the Bureau of Planning, the Guam Energy Office, and the Public Utility Agency of Guam. The reports and information obtained from these agencies, and used for this report, are listed in the Bibliography.

The second phase of this study was the description of scenarios of hydro development. Based on standard hydro construction cost, five sets of hydro strategies were examined and discussed. These strategies are:

1. Plant at Existing Impoundment Area
2. Plant at Proposed Impoundment Area
3. Plant at Existing Distribution System
4. Plant at Undeveloped Site
5. Small Scale Site Development

Factors affecting the prioritizing include net generation potential, development cost, use points of services, and environmental impacts.

The next phase of the study was Inventory Assessment. The existing water facilities were examined, and their physical condition, capacity for hydro potential, and location relative to nearby use points were noted.

Then, the author studied the 32 major drainage basins of Southern and Central Guam. Each drainage basin was isolated, and on each isolation map existing data were recorded. Known guaging stations and the average measurements were recorded on maps which already contained contour markings showing elevation. Sites were checked for head/flow combinations, and those potential combination points were rechecked on larger maps to determine nearness to infrastructure and possible use points. Flume and penstock lengths required to optimize head/flow combinations were sketched onto the maps on areas which lacked naturally existing high head/flow combination points. A power projection program was developed to quickly project potential hydroelectric generated power at any location. This program was used to target sites with the best combination of data. These sites were recorded, to be later ranked in terms of development potential.

The author then investigated the hydro potential at the Proposed Ugum River and drainage River Dam sites, using the data developed by the U. S. Army Corps of Engineers. The hydro potential at the sites were calculated considering a varity of flow conditions ranging from the lowest projected dam run-off to the total discharge presently targeted to be used for farming and irrigation.

The final part of this phase uses the solicitation of current equipment notes and price quotes for the components of the hydro plant from off-island companies ranging in location from Japan and the United States Mainland to European manufacturers. These notes and price quotes are incorporated into the report and support the cost benefit calculations used to develop the economic sections contained herein.

The fourth phase of the study was the discussion of relevant economic considerations. In this phase the impact of water sales and rising cost of conventional energy versus alternative energy development are addressed.

The final phase is the development of conclusions and recommendations.

H. SCOPE OF STUDY

Guam, similar to many other geographic locations, is faced with an energy/environmental trade-off situation. Local and national policies mandate action to limit negative environmental impacts in construction, and in the operation of public and private enterprises. In the case of energy enterprises, the environmental aspects are closely tied to and effect the choice of energy source, its mode of development, and even its subsequent operation. In hydro generation, the environmental issues represent limitations mainly in the initial stages of development. In dam construction, water body diversions, etc., there are obvious immediate negative environmental impacts. Regardless of how these are weighed against the long range impact when compared to conventional sources of energy, particularly fossil fuel sources, they still limit the scope of the study.

The following are three statements of local and national policy that set limits to this study:

> Agencies should ...include in the decision-making process appropriate and careful

> consideration of all environmental effects of proposed actions...[and to] avoid or minimize adverse effects of proposed actions and restore or enhance environmental quality as much as possible....
>
> Fed. Reg. Vol. 40, #72 @16815
> Section 6.100 re
> National Environmetal Policy
> Act of 1969

> It is...the public policy of Guam...that a high quality environment be maintained at all times...and that environmental degradation of all land, water, and air...should not be allowed.
>
> P.L. 11-91
> GEPA Enabling Legislation

> The national objective of attaining a greater degree of energy self-sufficiency would be advanced by providing Federal financial assistance to meet state and local needs resulting from new or expanded energy activity in or on the coastal zone.
>
> CZMA Amendments of 1976
> P.L. 94-370
> Section 302(i)
> Congressional Findings

Another factor that affects the scope of the study is the amount and quality of flow duration measurements. Some of the hydro sites, suspected to be better sites, are not guaged at that particular point. The author was obligated to estimate stream flow, using U. S. Army Corps of Engineers methodology, at these sites, resulting in approximate calculations.

In terms of the number and detail of the site calculations to be performed, obviously, detailed calculations for every linear foot of waterway on Guam could not be funded under this project. One of the functions of this study, nevertheless, is to appraise hydro potential in more than one scale and application.

For this reason, the study will address both small and large scale applications as discussed in the study goals.

I. PREVIOUS INVESTIGATIONS AND PRESENT WORK

Prior to this study, there has been limited investigation into the hydroelectric generation potential of Guam. On June 13, 1980, the Guam Energy Office received a letter from Mr. W.D.C. Murray, representing Engineering & Power Development Consultants, Ltd., England. Mr. Murray states in his letter:

> ...We have found that the [hydroelectric] potential is disappointingly low; largely because long downstream reaches of most rivers, where the flow is greatest, are at low elevations.
>
> In the upstream areas, where appreciable changes in level occur, the flows are small, and so is the available energy.
>
> Although there are perhaps five sites that might economically be developed and could justify their costs in the value of oil saved, the installed capacity would be too small to interest other than a private consumer. No site would have a capacity greater than 150 kW; obviously insignifigant compared with the maximum demand on Guam of 150 MW.

This is the only known recorded estimate to date for hydroelectric generation potential. However, there was no indication of the methodology used in the formulation of this estimate.

Pacific Energy Management Consultants, Guam, under the same CEIP funding source, are presently studying waste water low-head hydroelectric power systems on Guam.

These in conjunction with this study represent the total in hydroelectric investigations for Guam.

J. ACKNOWLEDGEMENTS

We would like to acknowledge the pertinent statistical data supplied by Mr. Charles Huxel, USGS, and Mr. Frank Dayton, U. S. Army Corps of Engineers, and the technical guidance of Mr. Walter F. Pinckert, P.E., of W.F. Pinckert & Associates.

We further wish to express our sincere appreciation to Mr. Jay Lather, Director of the Guam Energy Office, who made this report possible.

NOTES FOR CHAPTER I

1. Leslie M. Price, "Power From Water", Power, April 1980 pp. S.1-S.2

2. Ibid.

3. Ibid.

4. Ibid.

5. Ibid., pp. S.5-S.8

6. IOAHO National Engineering Laboratory, Small Hydro Bulletin U. S. Department of Energy Report, Vol. 2, No. 4 December, 1980

Chapter II

II. HYDRO STRATEGIES

A. OVERVIEW

This section describes the typical requirements, costs, and impacts of hydroelectric development relative to five implementation strategies. These stragtegies are: development of a hydro plant at existing impoundment areas; at proposed impoundment areas; at existing distribution systems; at undeveloped sites, and at small scale sites.

B. BASIC HYDRO REQUIREMENTS

Any scenario of hydro development must address and include some very basic components. To create a potential for power, a site must have flowing or accumulating water, that falls a vertical distance. This fall, however, cannot be open flow in a flume or over a waterfall. The pressure which produces the power must be created, either by damming the water or by transferring it from one elevation to a lower elevation in a pipe or penstock.

The simplest power plant would be comprised of a pipe that flows from a high elevation to a lower elevation, a pump installed in the pipe in reverse flow, a generator to create electricity from the spinning pump shaft and a means to distribute the electricity or store it.[1]

This type of power plant has limited applications, however, and the usual hydro site has more requirements. The majority of these requirements, and, consequently, the costs for the hydro plant, go to the civil works, particularly at potential sites with no existing dam structure. The first requirement is a dam or reservoir.[2]

Dams are classified by their function. A dam designed to relocate the water for irrigation, or to a power plant, for instance, is called a diversion dam. Because these dams provide little or no storage they create little or no head.

Dams that are designed to retain larger bodies of water which can be used to regulate or augment the river flows in order to compensate for variances in natural flow are designated storage dams.[3]

Generally speaking, storage dams cost more than diversion dams, because diversion dams entail less construction. There is no simple "rule of thumb" estimation for dam cost in hydro applications, since there are many different types of dams which may be made from different materials. Relative to the total hydro poject, however, the dam consumes generally half of the project costs.[4]

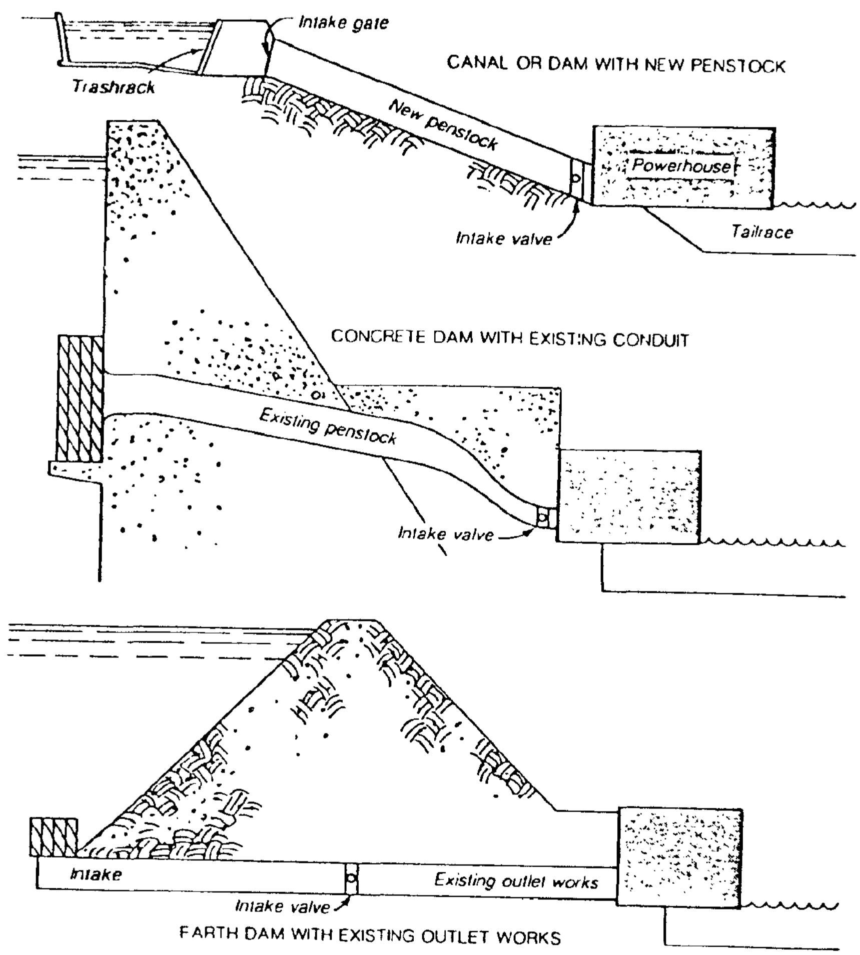


Figure 2-1

Figure 2-1 shows three different dams and outlet trunks for hydro plant designs. The top figure shows a new penstock and intake addition to an existing dam or canal. The middle figure shows a concrete dam, the normal type for Guam, with existing conduit. The bottom figure is an earth dam with existing outlet works.[5]

On Guam a necessary addition to any dam is a spillway. The function of a spillway is to divert floods or excess flows or allow them to pass safely over the dam. Spillway costs are directly related to the size of the anticipated maximum river discharge at the dam. Other types of control devices at the dam include radial gates, drum gates, slide and wheel gates, flashboards, stoplogs, soldier beams and bulkheads. For any hydro installation a competent designer must analyze the stream data and proposed dam site to determine the necessary dam components.[6]

Another basic civil component to a hydro site is the outlet works. This allows a controlled stream of water to flow to the powerhouse from the reservoir. This could consist of a tunnel or a penstock but it must include an entrance channel, trashracks, an intake structure, a waterway, a water control system, bypass valves, and any operation or maintenance tunnels or access shafts.

Regarding penstocks, it should be noted here that in the analysis of the river power characteristics it was repeatedly found that because of the relatively low power output potential of the sites, those which required long penstocks were not economically justifyable. There are locations which were investigated, particularly Almagosa Springs (elevation 640 +/- feet) which have attractive head potential. Economic problems accompanied these development scenarios in the form of costs for penstocks which would survive the high pressure stresses while not losing substantial head due to reduced pipe diameter. Several pipe diameters were considered and their loss in head calculated. The result was disapointing. Even a 12" pipe loses about 65 feet of head per running mile, while costing as much as $40.00

to $50.00 per linear foot to lay on the ground surface. Smaller diameters are less costly but lose more head, defeating the purpose of developing high head sources, which require miles of penstock.

The final civil component to any construction site is an access road. There must be access to the site in the form of a road capable of transporting equipment, tools, and persons. At a cost of about $25.00 per linear foot or $132,000.00 per mile, this is another component that can financially make or break a small hydro project.[7]

C. HYDRO SCENARIOS

1. Plant at Existing Impoundment Area

Figure 2-2 shows two pie graphs depicting maximum and minimum civil-feature costs. The minimum civil feature graph is for projects having existing outlet works, which require limited penstock and other waterway-passage costs. The other graph indicates projects with major outlet works requirements such as long penstocks or major alteration of existing outlet works.[8]

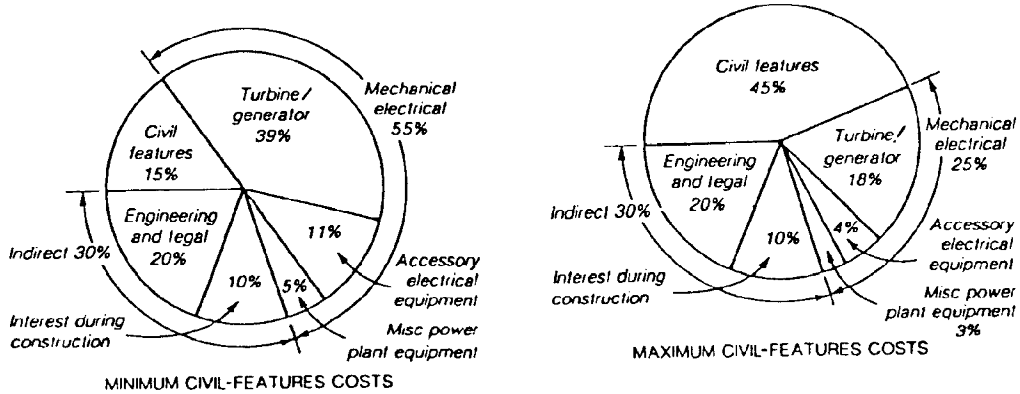


Figure 2-2

Unfortunately, there is no standard package for adding a small hydroelectric plant to an existing dam or for even designing a new site. The type of dam, the site data, the dam function, the type of outlet works required, the nearest location for an electric power grid, all shape design decisions and affect construction costs.[9]

Using an existing impoundment area can radically cut costs as well as other design concepts such as:

a. Using all reliable and useful parts of the existing structure;

b. Avoiding limiting the use of coffer dams and bulkheads or other temporary structures;

c. Increasing the available head and corresponding power potential by using collapsable flashboards and gates;

d. Eliminating, where possible, buildings designed only for water production. One must be careful here, because many of the Public Utility Agency of Guam equipment installations are suffering from deterioration, due to exposure to local elements.

Environmental impact. The degree to which the hydroelectric installation will affect the surrounding environment depends on the plant's site, its design, the way it is operated, and the way it is constructed.[10]

By installing a plant at an existing dam, environmental difficulties can be kept to a minimum. Dam construction constitutes the major negative environmental impact and at an existing dam the surrounding flora and fauna have already adjusted to the major changes. Since no major excavation is required, there are no problems relative to damaging historical or archeological sites. The environmental stress during construction is limited to the minor, temporary disturbances that happen while the plant is being installed, and to the visual infringement of the transmission lines required for power distribution.[11]

Negative impact could result after completion of the power plant if the flow-release patterns radically affected the upstream water levels to the extent that it interfered with the fish and wildlife habitats.[12]

Potential sites. Four major impoundment areas are addressed in this study. These are Asan Spring Basins, Santa Rita Spring Basins, Geus River Dam, and Fena Valley Reservoir. Of these, the only potentially developable site is the Fena Dam, which is addressed thoroughly in Chapter V, Existing Water Facilities; Section A., Impoundment Areas.

2. Plant at Proposed Site

There are seven proposed sites for development of surface water storage. These are located in the following drainage areas:

a. Ugum River

b. Inarajan River

c. Umatac River

d. La Sa Fua River

e. Talofofo River

f. Finile River

g. Agana and Janum Springs

The recommended points of development are shown on the drainage area maps included in this study, complete with their coordinates in meters.

These locations could cut hydro installation costs in the same ways mentioned in the previous discussion, "Plant at Existing Impoundment Area."

The priority of development is ranked in the <u>Surface Water Survey</u> by Austin Smith and Associates, Inc., June 1968.[13] The following prioritization schedule comes from that report and is included below:

> <u>Priority No. 1</u>
>
> The first new surface water source to be developed should be the Ugum River above Talofofo Falls. This source, when fully developed, is of sufficient size to provide all supply requirements of the Southern and East Coast demands through 1995. The Ugum development can be the primary source for the villages of Yona, Talofofo, and Inarajan, and can also provide the alternate source for Merizo and Umatac when the distribution systems are extended to these villages. Any surplus available over and above the requirements of the villages can be transferred through the 12 inch Yona-Chalan Pago transmission pipeline of the FY67 Water System Improvements Program

to the Central Area System.

Priority No. 2

The second source development under discussion in this report should be that of Agana Spring. Upon the completion of the FY68 Water System Improvements, two one million gallon reservoirs at Agana Heights and Tumon could receive this water for storage and distribution. As these reservoirs have overflow elevations of 190 feet, some one hundred feet lower than the reservoirs of the remainder of the central system, the pumping costs from Agana Spring to the system will be less per unit pumped than any other source other than Asan Spring.

As Agana Spring is centrally located, the development of its source will relieve some of the draught presently being exerted on the Dededo well field by the Tumon and Tamuning areas. It appears that the development of Agana Spring can be accomplished by either a battery of wells or by a central pumping station and treatment plant. Because of its central location and the close proximity of both commercial business establishments and private residences, the minimum treatment of chlorination must be considered a requirement under either form of development.

Priorities No. 3 and No. 4

Depending on the growth pattern and the population build-up, the third development should be the Umatac-La Sa Fua Rivers or the Talofofo River.

If resort areas and residential development takes place along the western coastline around Cetti Bay or in the rolling hills area south of Agat, the Umatac-La Sa Fua development should be next. This would provide water for Umatac, the developments and Agat-Santa Rita through a new water line along Route 2. During periods of higher flows some of this water could flow southward also to Merizo through a future transmission pipeline.

On the other hand, if developments continue in the Windward Hills area and along Route 17 north of the Naval reservation, the Talofofo River development should precede the Umatac-La Sa Fua improvements.

Priority No. 5

Inarajan River would next be developed to improve the supply along the eastern and southern coastlines. This development appears to be less desirous than the Ugum because of the sediments found in the stream which will require more exacting and additional treatment. The reason for development of this source is not so much to augment the Ugum supply for the eastern and southern shores, but rather to become the primary supply for this area, thereby releasing the Ugum River water for further augmentation of the central area system as demands there rise beyond the limits of the well fields.

It is considered probable that prior to the year 2000 booster stations will be transmitting as much as three million gallons per day northward into Chalan Pago and Mangilao to improve the supply of the central system. By that time, the Barrigada, Chalan Pago, Chaot, Afame and Dededo wells will be delivering their supplies to the areas lying north and east of NAS Agana.

Priority No. 6

Under present population distribution and expected growth curves, the Janum Spring development is recommended to be last, not because of lack of water requirements in the vicinity, but because of unit costs of development. The required high lift to the Yigo plateau and the relative incaccesibility to the spring are the main deterrents to its immediate or immediate future development.

Conditional Priority No. 7

Left to the last for discussion purposes, but not necessarily last in actual development, is the Finile Stream and spring at Agat. This development must and will remain small because of the relatively limited supply and the scarcity of water available during drought seasons. This source also has its political innuendos, too. At present, the ample Navy supply provides water to this area and the Government of Guam purchases this water directly from the Navy for distribution. Should the Territorial Government desire to divorce itself completely from the Navy, then this system must be developed to its fullest, but it must also be augmented from another source.

It has been our thinking that all Navy sources to the Territorial Government be curtailed elsewhere throughout the island first, leaving this civilian area, which lies near the Navy source, on the Navy supply entirely.

Should the Government of Guam wish to phase its water system off the Navy supply, this development could proceed immediately, providing some 300,000 gallons of water to the civilian population of Agat and Santa Rita about 75 percent of the year. A metered, air break Navy supply that is float controlled could be provided at some reservoir site above either Agat or Santa Rita Villages. When the Finile supply falls below demand requirements, the Navy augmentation supply could flow into the system.

Later, when the Umatac or Talofofo developments have been completed, these sources could then replace the Navy augmentation.

The timing and development of this source, therefore, is dependent upon the political aspects and business arrangements of the United States Navy and the Territorial Government of Guam.

These sites were ranked for domestic water supply and are not necessarily the best sites for hydro generation in these areas. The Agana and Janum Springs are not potential hydro sites. All of the other river basins mentioned have hydro potential at the proposed locations in these areas:

Ugum River. The dam proposed by the U. S. Army Corps of Engineers will create a potential head of about 100 feet and with the flow and design storage requirements is the best hydro site on the island. The potential is discussed further in Chapter IV, The Rivers.

Inarajan River. The dam proposed by the U. S. Army Corps of Engineers will create a potential head of about 100 feet. Based on this data and the flow records for the river, this is ranked second among the potential sites.

The rest of the proposed impoundments lack data describing the proposed dam and its dimensions. Assuming a dam height of 50 feet the next best sites, in order, would be:

a. Talofofo River
b. Umatac River
c. La Sa Fua River

The Finile stream has a very low discharge and is known for dry periods. It is therefore a low priority site for hydro development.

The targeted points of development for the Ugum, Umatac, and La Sa Fua Rivers lie at high elevations, 200 +/-

feet and 300 +/- feet, respectively. In each case the target location falls on a stretch with a high gradient. This means that each site has good potential for developing head, even if the proposed dam lacks substantial height.

It should be noted that should these sites be developed to augment the domestic water supply of a village then any potential head at the site will be used to satisfy or defray the pumping requirements. Consequently, any hydroelectric generation at these sites would be limited to that which could be produced by the existing head at the proposed dam using the discharge designed to maintain stream flow. In the case of high flow periods, the flow would be boosted by water that would otherwise have been diverted over the spillway as excess.

Without having more information on the proposed dams on the Umatac, Talofofo, and La Sa Fua Rivers, it is impossible to make detailed economic projections relative to the cost effectiveness or payback period of a hydro plant addition.

Environmental impact. The environmental impacts here are the same as discussed in the previous section, "Plant at Existing Impoundment Area."

3. Plant at Existing Distribution System

In rare cases in the development of a fresh water or waste water removal system, the situation arises in which a pipe transmits water or waste from a high elevation to a lower one, creating a pressure diferential capable of doing work.

This happens at several locations on Guam in the fresh water systems, but not to the extent to be commercially developable.

There is, however, a case presently being studied in Northern Guam, where waste water is dropped in a pipe from a high altitude plateau to sea level, creating a cost effective hydro site.

This case is covered in detail in the study for the Guam Energy Office, entitled Waste Water Low-Head Hyroelectric Power Systems on Guam, conducted by the Pacific Energy Management Corp., Guam.

Environmental impact. A major bonus of a system like this, is that it is totally self-contained, and therefore constitutes no environmental threat.

4. Plant at Undeveloped Site

Obviously, the toughest way to economically justify a hydro plant is to start at a totally undeveloped site. On Guam, it is particularly difficult because the average potential hydro installation is too small to offset the substantial start-up costs.

To better illustrate this, consider a particular site. Site "X" is located on the Imong River, on a stretch that falls 80 vertical feet over a river length of 4,000 feet. The average flow in that section is 6.59 mgd and the 90% flow case is 1.1 mgd. The developable head is 40 feet, using a 1,000 foot penstock, and the planned point of use is one mile from the site. The nearest access road is one-half mile from the site.

Cost of development. The first cost incurred must be the extension of the access road, which costs about $130,000 a mile. The design plans for half a mile of road at a cost of $66,000.00.

The design calls for a small diversion dam, at a cost of $15,000.00 and 1,000 feet of penstock at a cost of $40,000.00.

Once the plant is generating electricity, it must be delivered to some use point. This design calls for one mile of transmission lines at a cost of approximately $144,000.00. The total cost at this point totals $265,000.00.

A 20 kW plant will cost about $32,000.00 and will generate about 117,000 kWh in one year. To buy this electricity at $0.10/kW would cost $11,700.00. Applying this amount towards a 30 year loan with equal annual payments at 10% interest, one could borrow $110,294.90.

This means the plant is not nearly cost effective, as designed. However, consider the same case with different features. First assume the access road runs very near to the site and only has to be slightly improved at a cost of $5,000.00. Next the power is to be used at a farm adjacent to the site. The cost of electrical hookup is $4,000.00. Furthermore, the designer chose a good natural spot that develops 20 feet or half of the head with a minimum length of penstock, say 80 feet, at a cost of $3,200.00. He choses to intall a 10 kW plant that will cost $25,000.00 and will generate 58,500 kWh in a year. Add to this 10% for design and legal fees - the unit is a prepackaged unit, the site is small, and he does not encounter much environmental resistance or legal problems. His total costs are now $57,420.00. With the same financing constraints, based on the new amount he can generate, his borrowing power is $55,147.45. Should the cost of energy rise at all, the site is cost effective.

This scenario shows the impact of the costs of the civil works features. Note that a diversion dam was used in this case, not a more expensive storage dam. Independent of the dam, the potential undeveloped site's cost effectiveness is not limited to the amount of power it can produce. The civil works features, due to their high relative expense, must be kept to a minimum for a site to have a financial prayer.

The author has taken this a step further by analyzing the possibility of diverting and combining river branches to increase flow and thereby increase power potential. Several river basins such as the Talyfac River, Cetti River and Inarajan River have configurations similar to that shown in figure 2-3 in two to four of their branches.

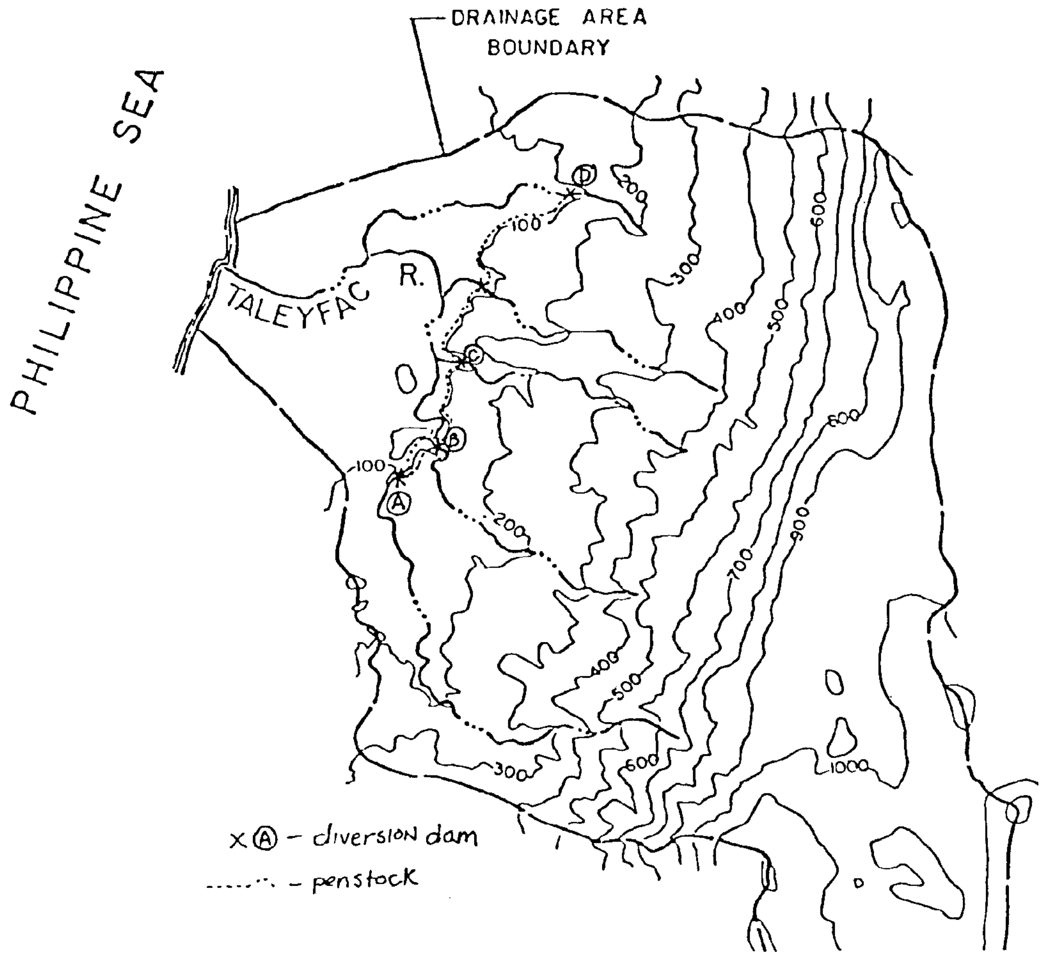


Figure 2-3

In each case calculations were made to estimate the cost of constructing diversion dams at points A, B, C, and D to divert the stream flow via flumes and penstocks to form one main body of higher flow.

In every case the cost of combining the flows far exceeded the benefit of increased power potential.

Environmental impact. The degree of environmental impact caused by the construction of a hydro site is directly related to its size. The construction of a small scale home or farm plant would have no more negative impact than the installation of a Public Utility Agency of Guam domestic water station. Larger sites require more land to be razed and inundated. Reservoirs and dams produce permanent alterations to the land and stream. The effect is not as great in populated areas that made the adjustment long ago. However, in pristine areas on Guam (Ugum), specimens of rare plants would be eliminated due to the impacts of construction, although no species would be totally eradicated.[14]

Another major environmental impact would be the removal of upstream breeding grounds for most diadromous fishes, crustaceans, and limpets on Guam. This effect would be gradual and subtle.[15]

A typical dam construction would also create problems of turbidity, erosion, and increased levels of airborn hydrocarbons and dust. Clearing and grubbing of surface vegitation in the construction process also increases the likelihood of accidental fire and consequent air pollution.[16]

Impounding the water creates its own problems. Spawning-in-stream fauna is influenced by stream discharge volume, flow duration, and seasonality, all of which would be changed by the impoundment of water in a reservoir. The release of the water will have different temperature, oxygen content, pH and sediment content from the orginal conditions.[17]

A final impact is the potential distruction of archeological sites or artifacts in the impoundment area.[18]

5. Small Scale Sites

In terms of hydro generation capacity a small scale application is considered to be less than 10 kW. Since there are no existing hydro sites of this size that may be renovated, new sites at houses and farms would have to be started without the cost benefits of an existing usable structure. As indicated in the previous discussions, the conditions have to be optimal for a new site to be cost effective.

First, the home or farm owner must live adjacent to a water body with the head/flow combination necessary to support the installation. In the Chapter IV, The Rivers, many stretches are mentioned that have the characteristics for this size range.

Second, near to the prospective point of use, there must be a suitable impoundment area. The area must be examined by a soils expert, otherwise thousands of dollars would be spent on a dam that leaks.

Third, the plant must be able to develop adequate head with minimal lengths of penstock (generally less than 100 feet in length).

Fourth, there must be a road in the immediate vicinity of the site, to deliver the equipment and construction materials.

In the case of a farm application, off season labor can be used for the plant and dam construction, thus cutting costs.

In terms of power plant costs, a 5 kW self-contained hydro plant costs about $23,000.00 to buy and ship to Guam, and a 10 kW plant about $25,000.00. If an owner wishes to have this system payback in 20 years at today's electrical costs, he must be able to install the plant and pay for all of the civil works for under $64,000.00. To be able to pay the loan that would provide this amount, his plant must generate 43,800 kWh in a year for 20 years.

NOTES FOR CHAPTER II

1. Leslie M. Price, "Power From Water", Power, April 1980 pp.S.5-S.11

2. Ibid.

3. Ibid.

4. Ibid.

5. Ibid.

6. Ibid.

7. Ibid.

8. Ibid.

9. Ibid.

10. Ibid.

11. Ibid.

12. Ibid.

13. Austin, Smith & Associates, Inc., A Report Covering the Surface Water Survey of the Island of Guam Public Utility Agency of Guam Report, Agana, Guam, June, 1968, pp. 49-51

14. U. S. Army Corps of Engineers, Ugum River Interim Report and Environmental Impact Statement, Harbors and Rivers, Territory of Guam U. S. Army Corps of Engineers Report, Fort Shafter, Hawaii, January 1979, pp.25-27

15. Ibid.

16. Ibid.

17. Ibid.

18. Ibid.

Chapter III

III. DESCRIPTION OF THE STUDY AREA AND ITS RESOURCES

A. THE STUDY AREA

The following is a section from the Hydrology of Guam by Porter E. Ward, Stuart H. Hoffard, and Dan A. Davis (1965),[1] which thoroughly describes the topography, climate, and geology of Guam as it relates to hydrography.

1. TOPOGRAPHY

> The northern half of Guam is a gently undulating limestone plateau bordered by steep wave-cut cliffs. The plateau slopes generally southwestward from altitudes of approximately 600 feet in the north to less than 100 feet at the narrow midsection of the island. The generally uniform suface is interrupted by three hills - Barrigada Hill (655 ft.), which is a broad limestone dome, and Mont Santa Rosa (858 ft.), and Mataguac Hill (630 ft.), which are composed of volcanic rock.
>
> No perrenial streams exist on the plateau because of the high permeability of the limestone. Water may flow in short channels in the limestone during heavy rains, but it soon disappears into numerous sink holes and fissures. Local runoff has eroded gullies in the volcanic rock of Mont Santa Rosa and Mataguac Hill, but here also the water sinks rapidly into the limestone that sorrounds the hills.
>
> The southern half of Guam is a rugged, deeply dissected upland underlain chiefly by volcanic rock. The surface is deeply channeled by numerous streams and eroded into peaks, knobs, ridges, and basins. A nearly continuous mountain ridge, running from the highland south of Piti to the southern tip of the island, lies parallel with and 1-2 miles inland from the

western coast. Several peaks in the ridge are 1,000 feet or more above sea level, the highest of which is Mount Lamlam, 1,334 feet above sea level. Along a part of the western coast an emerged limestone plain 200-300 feet above sea level and a little less than a mile wide lies between the ridge and the shore. Two projections of the limestone plain form Cabras Island and Orote Point at Apra Harbor. The relatively wide and gentle eastern slope of the mountain ridge merges near the coast with a narrow emerged limestone plateau that stands 100-350 feet above sea level and extends from Pago Bay south.

2. CLIMATE

The description of the climate of Guam is based largely on a study made by Blumenstock (1959).

Guam is warm and humid. The mean annual temperature near sea level is about 81°F; monthly means range from about 80° in January to 82 1/2° in June, and recorded extremes range from 64° in February to 100°, also in February. The relative humidity ranges from 66 percent in the early afternoon to 89 percent in the early morning.

Easterly trade winds are dominant throughout the year, and they blow 90 percent of the time from January through May. Calms are rare from January through May and are frequent from June through October. Trade-wind speeds generally are between 4 and 12 mph (miles per hour) and rarely exceed 24 mph, but typhoons passing over or near the island may bring winds having speeds greater than 100 mph.

Guam has two distinct seasons - a dry season from January through May and a wet season from July through November. December and June are transitional, or from year to year they may fall in either the wet season or the dry season. The mean annual rainfall ranges from about 80 inches on the coastal lowlands in the Apra Harbor area to about 100 inches on the uplands in southern Guam (fig. 2)[see fig. 3-1]. The isohyetal lines in figure 2 [see fig. 3-1] indicate somewhat less rainfall than was estimated by Blumenstock (1959, p. 15, fig. 4)[see table 3-2] and reported by Tracey and others (1964, p. A9). The difference is due to

TABLE 3-1. SUMMARY OF RAINFALL AT AGANA NAVAL AIR STATION, GUAM, 1952-62

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
AVERAGE	3.85	2.73	1.90	2.87	3.68	4.48	9.10	12.68	14.71	13.06	10.18	5.46	84.70
MAXIMUM	8.07	9.53	4.06	7.35	6.09	9.38	18.03	23.49	18.93	26.48	13.75	8.25	112.76
MINIMUM	1.34	.31	.58	.66	.66	1.20	4.74	7.37	9.82	9.36	6.78	2.14	63.57
MEDIAN	2.53	2.10	1.78	2.45	2.91	4.48	7.47	11.58	15.14	11.29	10.32	5.14	84.71

TABLE 3-2
PRECIPITATION STATIONS ON GUAM

	GEOGRAPHIC COORDINATES		PERIOD OF RECORD		COMPLETE YEARS OF RECORD	MEAN ANNUAL PRECIPITATION (Inches)
	LATITUDE (Degrees & Minutes)	LONGITUDE (Degrees & Minutes)	RECORDING	NON-RECORDING		
Andersen Air Force Base	13-34	144056	1947-77		27	90.51
Guam Naval Air Station	13-29	144-48	1956-77		19	88.19
U.S. Weather Station	13-33	144-50	1956-77		21	102.36
Mangilao	13-27	144-49	1973-77		4	101.03
Sumay	13-24	144-38		1905-40	33	88.45
Almagosa Springs	13-21	144-42		1952074	20	107.09
Fena Dam	13-22	144-42		1942-73	20	91.97
Fena Filter Plant	13-22	144-42		1954-76	22	96.11
Inarajan (NASA Dan Dan)	13-17	144-44		1952-71	15	93.40
Ylig	13-24	144-45		1952-75	22	89.81
Imong	13-20	144-42		1963-73	7	81.05

periods of record longer than those available at the time of Blumenstock's analysis. Of the total rainfall, 15-20 percent falls during the dry season, 68-73 percent during the wet season, and the remainder during the two transitional months. Dry-season rainfall is mostly from scattered light showers. During the wet season, about a third of the rainy days have prolongued and steady rain.

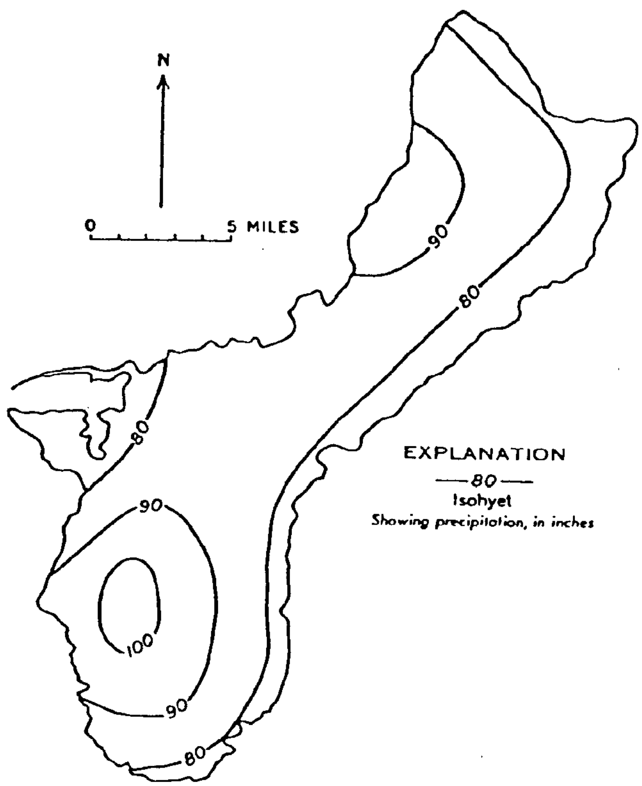


Figure 3-1

The heaviest prolonged rainfall on Guam is during the passing of typhoons. The greatest rainfall recorded during a 24-hour period in postwar years occurred during Typhoon Alice on October 14-15, 1953, when 24.90 inches fell at Anderson Air Force Base and 15.80 inches at the Agana Naval Air Station. The median of the rainfall at 12 widely scattered stations during the 5-day period of rainfall associated with the typhoon was about 24 inches.

Drought is common on Guam, and severe

drought is not unusual. A drought of several weeks duration may occur at any time between the first of December and the end of May, but the period of most frequent drought is February through April. According to Blumenstock (1959, p. 29), any month with less than 4 inches of rain may be called a drought month, and February through April may be expected to be drought months in all parts of the island in 3 out of 4 years. A summary of the rainfall at Agana Naval Air Station (table 1)[see table 3-1] indicates the variation that occurred in the period 1952-1962.

3. GEOLOGY

The stratigraphy, structure, and pertology of Guam are described in detail by Tracey and others (1963), Stark (1963) and Schlanger (1964) and the summary given here is concerned mainly with elements of the geology that affect the hydrology of the island. The stratigraphic units, their distribution, and water-bearing properties are described briefly in table 2.[see table 3-3]

The principal rock in the plateau of northern Guam is the Barrigada Limestone, which lies unconformably on an irregular surface eroded in volcanic rock of the Alutom Formation and is overlain by a veneer of the Mariana Limestone. The base of the Barrigada under most of the plateau is below sea level. The volcanic rock extends above sea level in an area of several square miles near the northern end of the island and projects through the limestone at Mont Santa Rosa and Mataguac Hill (pl. 1)[not shown]. Most of the limestone in the plateau contains numerous caverns, fissures, and other solution openings, which give the rock a high overall permeability. The volcanic rock has a low permeability.

The Agana Argillaceous Member of the Mariana Limestone underlies an area of several square miles in the southern part of the plateau at the narrow part of the island. It extends below sea level in the narrow part of the island and rests on a steep surface of volcanic rock dipping northward near the southwestern boundary of the outcrop, which runs from Pago Bay to Adelupe Point. The argillaceous limestone has moderate to high permeability.

The Barrigada Limestone and the

TABLE 3-3. ROCKS OF GUAM AND THEIR WATER-BEARING PROPERTIES

GEOLOGIC	FORMATION	GENERAL CHARACTER AND DISTRIBUTION	WATER-BEARING PROPERTIES
Pleistocene and Recent	Beach Deposits	Unconsolidated calcareous sand and gravel; consolidated beachrock in intertidal zone. Occurs irregularly along the shore, particularly in beaches in embayments.	Sand and gravel have moderate to high permeability and, below sea level, are saturated, mostly with brackish water but locally with small quantities of fresh water.
	Alluvium	Poorly sorted clay, silt, sand and small amounts of gravel occur chiefly in the bottoms of valleys, and muck and clay are in marshy estuarine deposits along the west coast. Maximum thickness is about 100 ft.	Most of the material is saturated with water a few feet below the ground service, but because of low permeability it does not release water readily. Water is fresh except at the shore.
Piliocene and Pleistocene	Mariana Limestone	A complex of reef and lagoonal limestone consisting of a forereef facies, a reef facies, a detrital facies, a molluscan facies, and the Agana Argillaceous Member. Underlies most of the north half of Guam; forms a broad marginal apron along the east coast between Pago Bay and Inarajan; and forms Orote Peninsula. Agana Argillaceious Member underlies the narrow waist of the island and is dominant in the apron along the east coast. Maximum thickness is greater than 500 ft.	Permeability of nonargillaceous limestone is generally very high but irregular. Where the rock extends below sea level, it commonly contains relatively fresh basal ground water, but numerous solution channels and fissures may promote sea-water intrusion in some places, especially in coastal areas. Permeability of the argillaceous member is moderate to high.

GEOLOGIC	FORMATION	GENERAL CHARACTER AND DISTRIBUTION	WATER-BEARING PROPERTIES
	Alifan Limestone	Generally massive, poorly to well-consolidated detrital limestone, recrystallized in some places. Forms caps on Barrigada Hill, Nimitz Hill, and the high ridge between Mount Alifan and Mount Lamlam, and crops out in small patches along the coast in the Apra Harbor area. Includes Talisay Member, at base made up of volcanic conglomerate, bedded marine clay, marl, and clayey limestone. Maximum thickness of formation is about 200 ft.	Permeability is moderate to high. Contains perched ground water in some places in southern Guam where it lies on less permeable volcanic rock. Is the source of several perennial springs. Talisay Member has low permeability, but clayey limestone yields water at small and mostly intermittent springs.
Late Miocene and Pliocene	Janum Formation	Well bedded tuffaceous limestone. Small lenticular deposits crop out in several localities along the northeast coast between Lujuna Point and Anao Point. Maximum thickness is about 70 ft.	Permeability low to moderately high, but does not contain water.
	Barrigada Limestone	Pure detrital limestone, fine grained and homogeneous, massive, and well lithified to friable. Underlies most of north half of Guam and crops out over a broad ring-shaped area in north-central part. Width of the outcrop averages about 1 mile. A southern extension of the outcrop encircles Barrigada Hill. Thickness probably is greater than 540 ft.	Permeability of the rock is high. Wherever it extends below sea level, it contains fresh basal ground water as much as 7 ft. above sea level. This rock supplies numerous wells.

GEOLOGIC	FORMATION	GENERAL CHARACTER AND DISTRIBUTION	WATER-BEARING PROPERTIES
	Bonya Limestone	Friable to compact clayey medium- to thick-bedded jointed and fractured detrital limestone. Exposed principally in small outliers in the Fena-Talofofo valley, in small patches on southeast side of Ugum River, in the Togcha River valley, and near Mount Santa Rosa. Maximum thickness is about 120 ft.	Generally high permeability, but because of its small extent it contains very little ground water.
Early Miocene	Umatac Formation	Predominantly a volcanic formation made up of the following members: Dandan Flow Member (basalt lava flows); Bolanos Pyroclastic Member (breccia, conglomerate, sandstone, and shale); Maemong Limestone Member (limestone and calcareous tuff); and Facpi Volcanic Member (basalt lava flows, shale, sandstone). Underlies most of Guam lying south of a line between Talofofo Bay and Agat Bay. Total stratigraphic thickness is greater than 2,000 ft. Extends below sea level throughout area.	Largely saturated with water below depths of a few tens of feet to a few hundred feet beneath the surface, but the rocks are poor water-bearing materials because of low permeability. A surficial mantle of granular weathered material commonly contains thin bodies of perched water that discharge at seeps.

GEOLOGIC	FORMATION	GENERAL CHARACTER AND DISTRIBUTION	WATER-BEARING PROPERTIES
Late Eocene and Oligocene	Alutom Formation	Fine- to course-grained well-bedded tuffaceous shale and sandstone, lenses of tuffaceous limestone, and interbedded lava flows. Includes the Mahlac Member consisting of thin-bedded to laminated friable calcareous shale. The rocks cover a large area in central Guam from the vicinity of Asan and Piti villages to Mount Jumullong Manglo and the northern environs of the Fena basin. Underlies younger rock in north half of Guam and crops out at Mount Santa Rosa and Mataguac Hill. Stratigraphic thickness greater than 2,000 ft. Extends below sea level through area.	Permeability is moderate in a few places but mostly is low. Saturated with water at variable depths below the surface, but yields water slowly to wells. Surficial mantle of weathered material contains small perched supplies in many places.

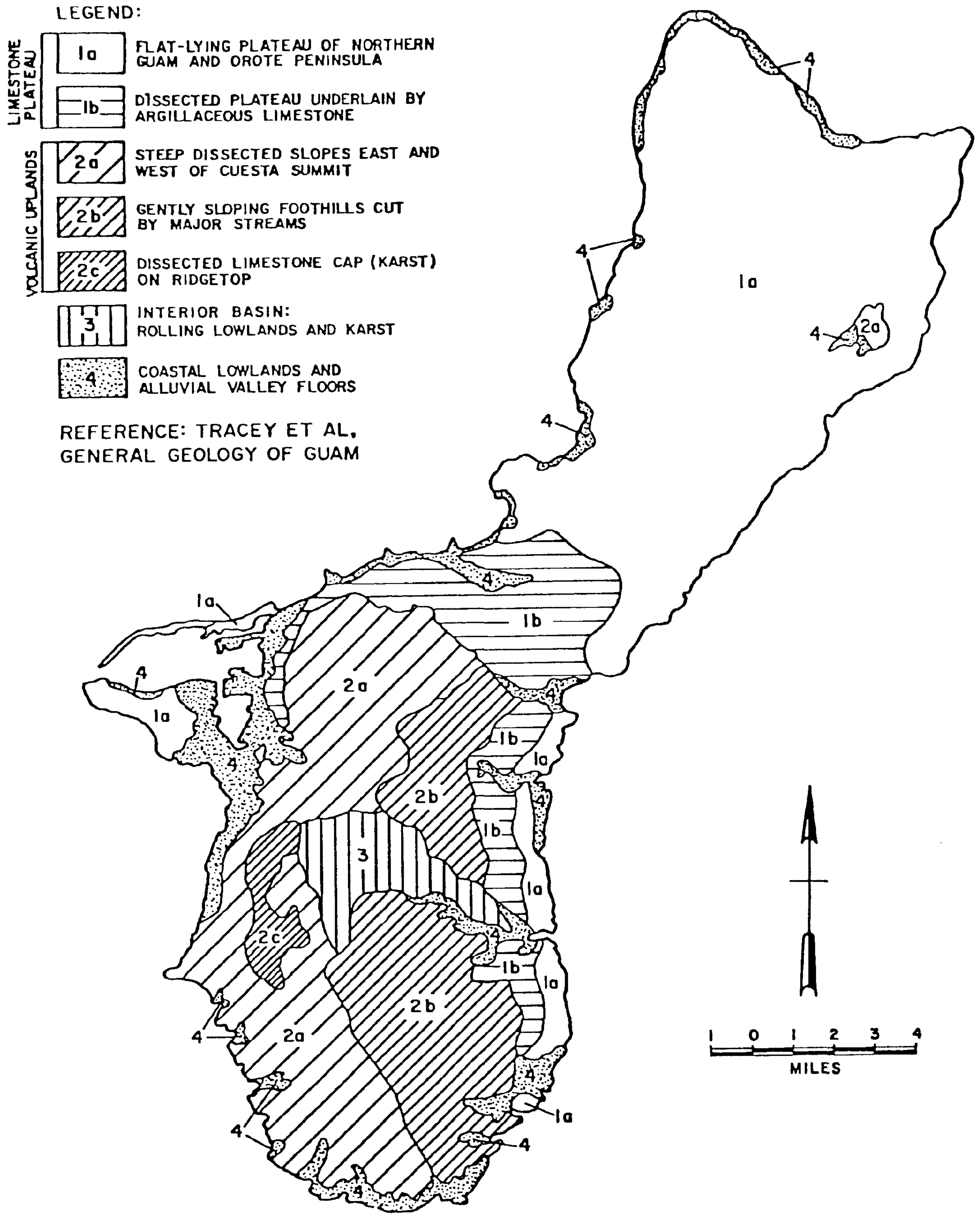


FIGURE 3-2

PHYSIOGRAPHIC DIVISIONS OF GUAM

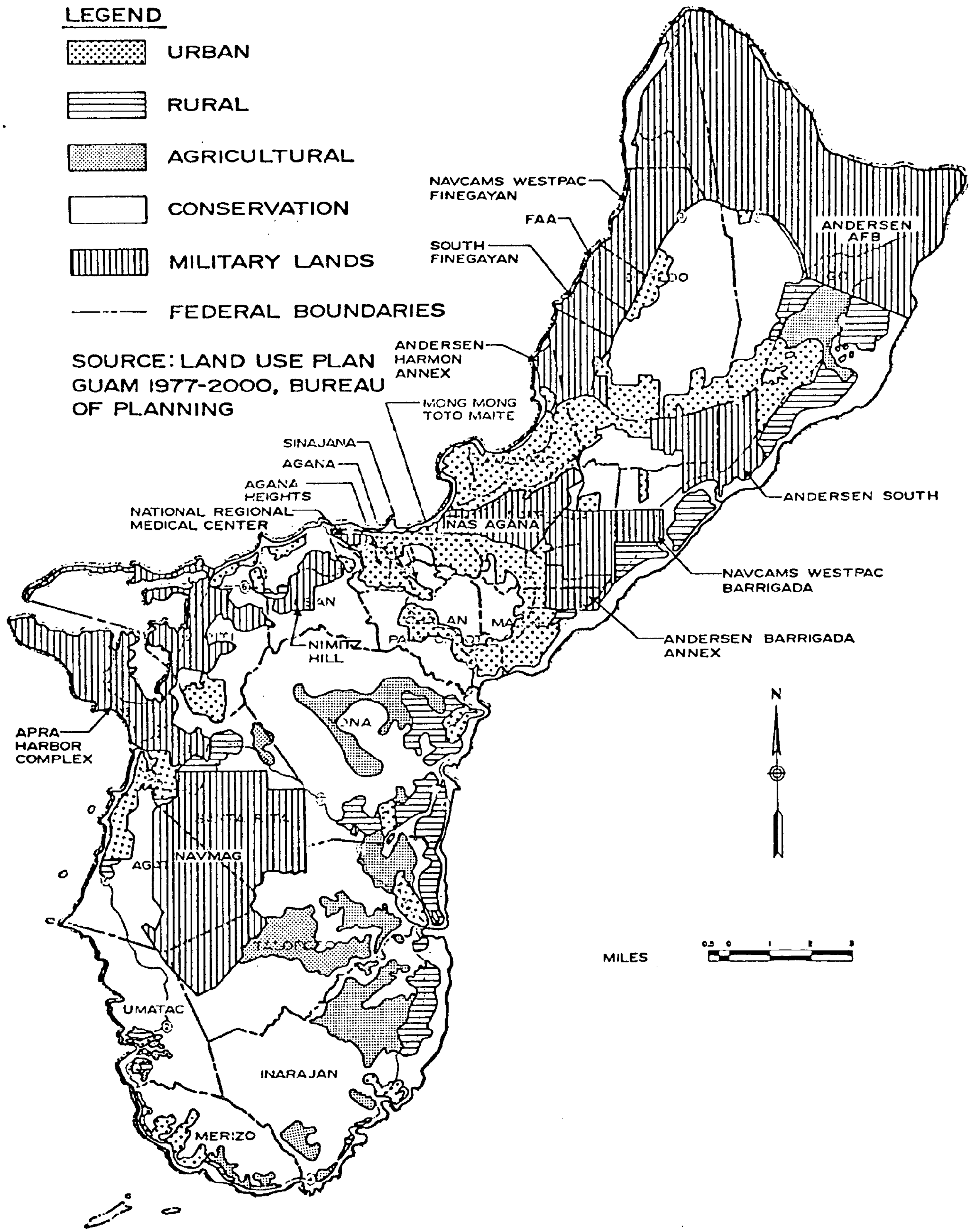


FIGURE 3-3

LAND USE MAP

SOURCE: 208 PLAN FOR
THE ISLAND OF GUAM

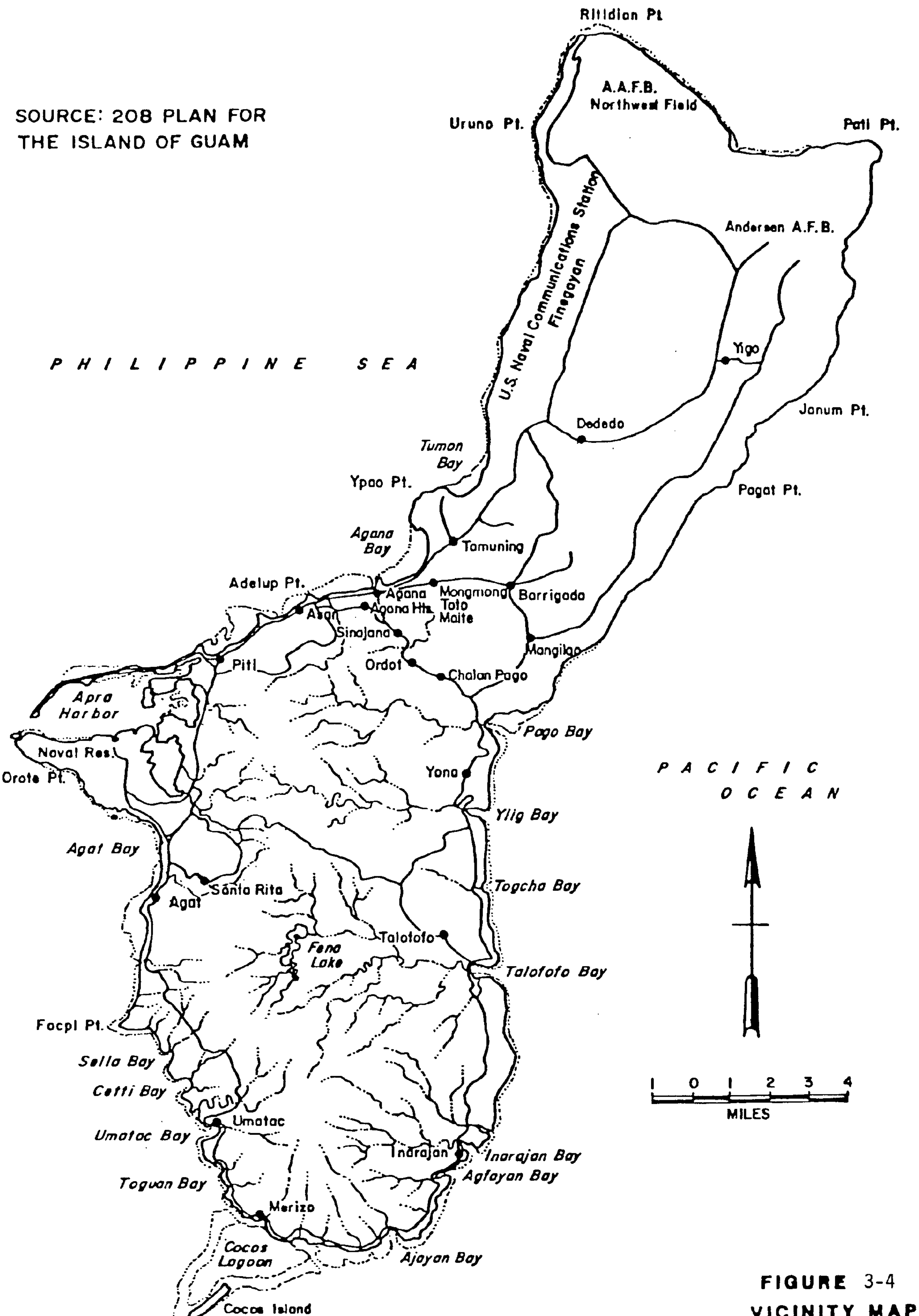
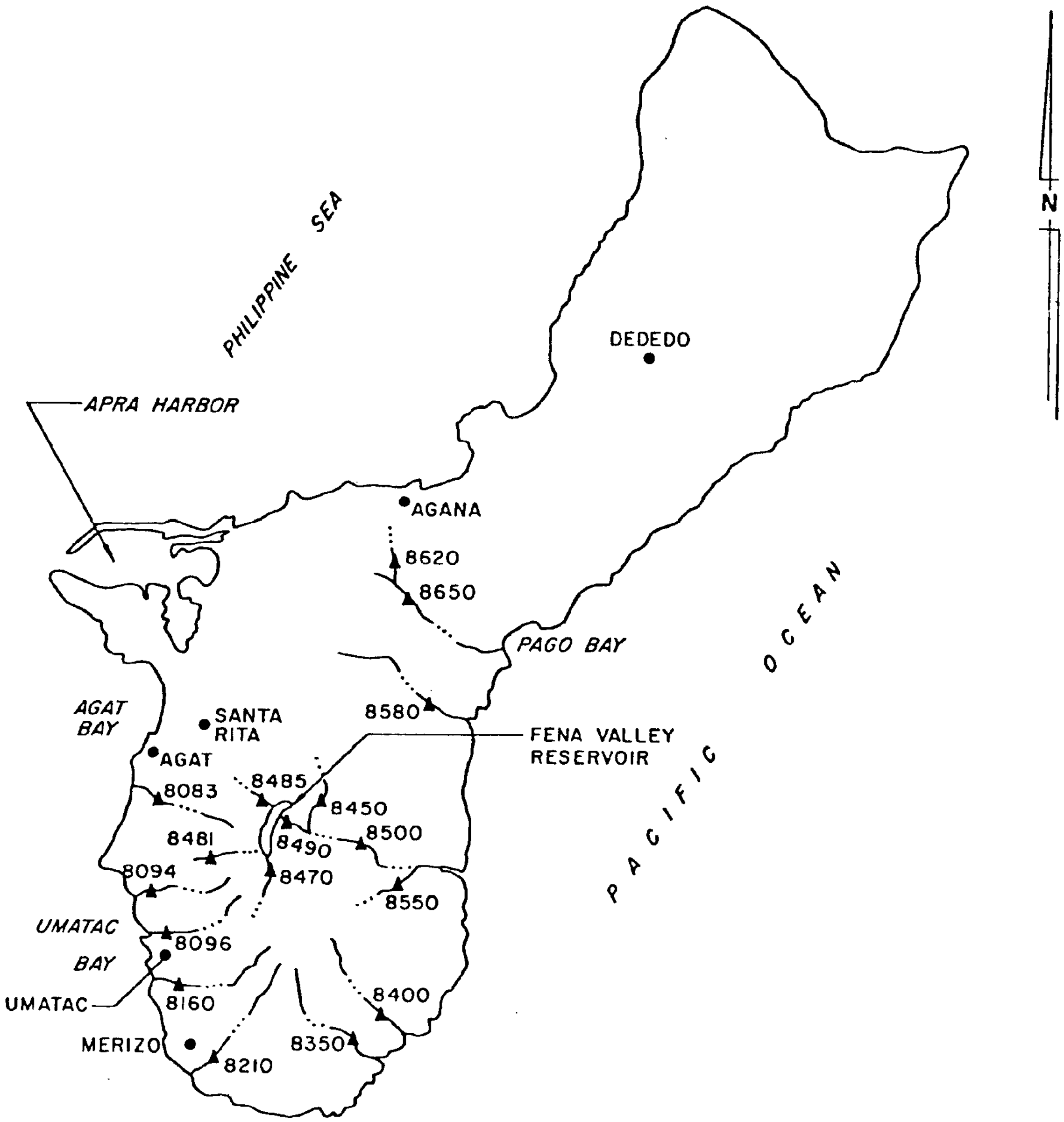


FIGURE 3-4
VICINITY MAP



LEGEND

▲ 8550 USGS STREAM GAGING STATION AND NUMBER

TERRITORY OF GUAM

STREAM GAGING STATION LOCATIONS

nonargillaceous facies of the Mariana are virtually pure limestone. They are overlain by a thin friable red soil, which contains considerable alumina and iron oxide and which is probably derived from material transported to the limestone surface. The Agana Argillaceous Member of the Mariana contains as much as 6 percent disseminated clay and locally as much as 50 percent clay in cavities and fissures. Much of the outcrop area of the argillaceous limestone is covered by several feet of clayey soil.

The rocks south of a line between Pago Bay and Adelupe Point consists mainly of a complex of pyroclastic rock and lava flows, clastic sediments derived from the volcanic rock, and small amount of interbedded limestone, which make up the Alutom, Umatatac, and Bonya Formations. Overlying parts of the complex are beds of the Alifan Limestone forming caps on peaks and ridges, and the Mariana Limestone forms marginal aprons along the coast.

The volcanic rock and elastic sediments are thoroughly weathered to depths of 50 feet or more over much of the area of exposure. The upper few feet of the weathered section is commonly granular and friable. The permeability of the fresh and weathered rock is low; the friable mantle is generally a little more permeable than the underlying material. The limestone lying on the volcanic and elastic rock has high permeability.

Unconsolidated deposits of alluvial clay having some silt, sand, and gravel underlie the floors of large valleys and form irregular narrow bands in coastal lowlands along the west coast. These deposits generally have low permeability. Moderately to highly permeable calcareous sand and gravel occur in discontinuous beach deposits along the shore.

B. HYDROLOGY

Of the nearly billon gallons of water per day that constitutes Guam's average rainfall, only a quarter flows to the sea as rivers and streams. Part of the water is lost to the atmosphere through the process of evaporation and

TABLE 3-5
RECORDING STREAM-GAGING STATIONS ON GUAM

USGS STATION NUMBER	STATION NAME	LATITUDE (Degrees & Minutes)	LONGITUDE (Degrees & Minutes)	PERIOD OF RECORD 1/	DRAINAGE AREA (Square Miles)	PEAK DISCHARGE OF RECORD DATE	PEAK DISCHARGE OF RECORD DISCHARGE (cfs)
8083	Finile Creek	13-23	144-39	1960-77	.28	21 May 76	326
8094	Cetti River	13-19	144-39	1960-67	.75	19 Oct 60	1,420
8096	La Sa Fua River	13-18	144-40	1953-50 1977	1.06	15 Oct 53	1,030
8160	Umatac River	13-18	144-40	1952-76	2.11	19 Oct 60	7,460
8210	Geus River	13-16	144-41	1953-75	.93	19 Oct 60	2,940
8350	Inarajan River	13-17	144-44	1952-77	4.42	11 Oct 63	Not Determined
8400	Tinaga River	13-17	144-45	1952-77	1.89	15 Oct 53	2,980
8450	Tolaeyuus River	13-22	144-43	1951-60	6.54	15 Oct 53	Not Determined
8470	Imong River	13-20	144-42	1960-77	1.95	19 Oct 60	3,370
8481	Almagosa River	13-21	144-42	1972-77	1.32	21 May 76	2,200
8485	Maulap River	13-21	144-42	1972-77	1.15	21 May 76	1,800
8490	Fena Dam Spillway	13-21	144-42	1951-88	5.88	15 Oct 53	Not Determined
8500	Talofofo River	13-21	144-44	1951-62	16.2	15 Oct 53	8,560
8550	Ugum River	13-20	144-45	1952-71	7.13	4 Dec 63	7,660
8580	Ylig River	13-23	144-45	1952-77	6.48	9 Sep 63	4,900
8620	Lonfit River	13-26	144-45	1951-60	3.11	15 Oct 53	Not Determined
8650	Pago River	13-26	144-45	1951-77	5.67	21 May 76	10,090

1/ Some records are not continuous.

TABLE 3-6
SUMMARY OF STREAMFLOW STATISTICS

USGS NO.	STATION	DRAINAGE AREA sq. mi	AVERAGE FLOW mgd	AVERAGE FLOW mgd/sq. mi	MINIMUM FLOW mgd	Q_{90} mgd	Q_{10} mgd	MAXIMUM FLOW mgd
8083	Finile Creek	0.28	0.92	3.29	0.03	0.13	1.9	211
8094	Cetti River	0.72	2.87	3.99	0.02	0.26	5.7	920
8096	La Sa Fua River	1.06	2.57	2.42	0.11	0.32	4.9	666
8160	Umatac River	2.11	5.62	2.66	0.07	0.52	11.0	4,820
8210	Geus River	0.95	1.95	2.05	0.00	0.06	3.6	1,900
8350	Inarajan River	4.42	11.2	2.53	0.27	1.29	20.0	Not Determined
8400	Tinaga River	1.89	3.68	1.95	0.10	0.26	6.5	1,930
8450	Tolaeyuus River	6.54	13.60	2.08	0.13	0.52	29.7	Not Determined
8470	Imong River	1.95	6.59	3.38	0.24	1.10	12.3	2,180
8500	Talofofo River	16.20	32.9	2.03	0.34	1.16	71.1	5,530
8550	Ugum River	7.13	19.0	2.66	0.71	3.30	40.0	4,950
8580	Ylig River	6.48	18.7	2.89	0.05	0.71	37.5	3,170
8650	Pago River	5.67	16.6	2.93	0.00	0.45	33.0	6,520

transpiration. The rest filters down through the soil and rock where it accumulates in ground-water reservoirs later appearing as springs and seeps that combine with streams or directly discharge into the ocean.

As indicated earlier, there are no streams that flow to the sea in the northern limestone plateau of Guam. There, the rainfall is percolated down through the permeable limestone, replenishing the aquafer and in cases flows to point of discharge at the shore. In the southern portion, however, the volcanic terrain does not readily absorb the water, and the bulk of the rainfall quickly forms rivers and streams that discharge into the ocean. This runoff averages 250 million gallons per day (mgd) and comes mostly from streams flowing on the eastern slope of the island.[2]

Beginning in 1950, guaging stations were set up on the 16 major streams to record average and low flow cases. Additionally, low flow measuring stations have been set up at 40 miscellaneous smaller streams and tributaries. Table shows thirteen guaging stations, their locations and data summaries. Individual flow duration curves based on guaging station recordings accompany the discussion on the individual streams where data permits.

Because the streamflow in the southern section is a direct function of the amount of rainfall, the greatest flows correspond to the wettest months, July to November. During the transitional months, December and January, records show a decline in flow, and in the dry months, February to April, the average flow is only a fraction of that of the rainy months.

C. ENVIRONMENTAL RESOURCES

The environmental resources of Guam show a range of man's impact on the island from pristine savanna and ravine forests to industrial developments. With respect to the development of hydroelectrical generation plants, the target area of the southern watersheds have environmental resources considered to warrent protective planning. These resources include scenic vistas, cultural resources and archeological areas, as well as the remaining fragile ravine forests and savanna ecosystems which are a part of the wetlands, streams and the erosion-prone watershed lands discussed in this study.[3]

Decisions on the use of the land in the study area will naturally effect trade-offs with the development of the land and water resources on the natural environment.[4]

Man's advent, introduction of non-indigenous species, and habitat modification have altered the terrestrial fauna of Guam.[5]

The terrestrial wildlife presently includes mammmals, amphibians, lizards, snakes, and crabs, as well as larger mammals in the savanna and ravine forests, Guam Deer, Carabao, and feral pig. Formerly plentiful, but now a rare dinner treat, the Marianas Fruit Bats inhabited the Fena Reservoir area.[6]

In the local streams and rivers aquatic wildlife abounds, and although none are unique to Guam, they include aholeholes, sleepers, gobies, freshwater shrimp, freshwater prawns, snails, and freshwater eel. Catfish, tucunare, mosquito fish, and tilapia are all fish that have been introduced sucessfully to Guam's reservoirs and streams. A variety of marine fishes travel well into the estuaries and even into the freshwater during segments of their life cycle. These include tarpon, mullet, and halfbeak.[7]

NOTES FOR CHAPTER III

1. Porter E. Ward, Stuart H. Hoffard, and Dan A. Davis, Geology and Hydrology of Guam, Marianas Islands Geological Survey Professional Paper No. 403-H United States Government Printing Office, Washington D.C.,1965 pp. H3-H6

2. Ibid., p. H6

3. U. S. Army Corps of Engineers, Ugum River Interim Report and Environmental Impact Statement, Stage I Report U. S. Army Engineers District Report, Honolulu, Hawaii, August, 1975 pp. 11-12

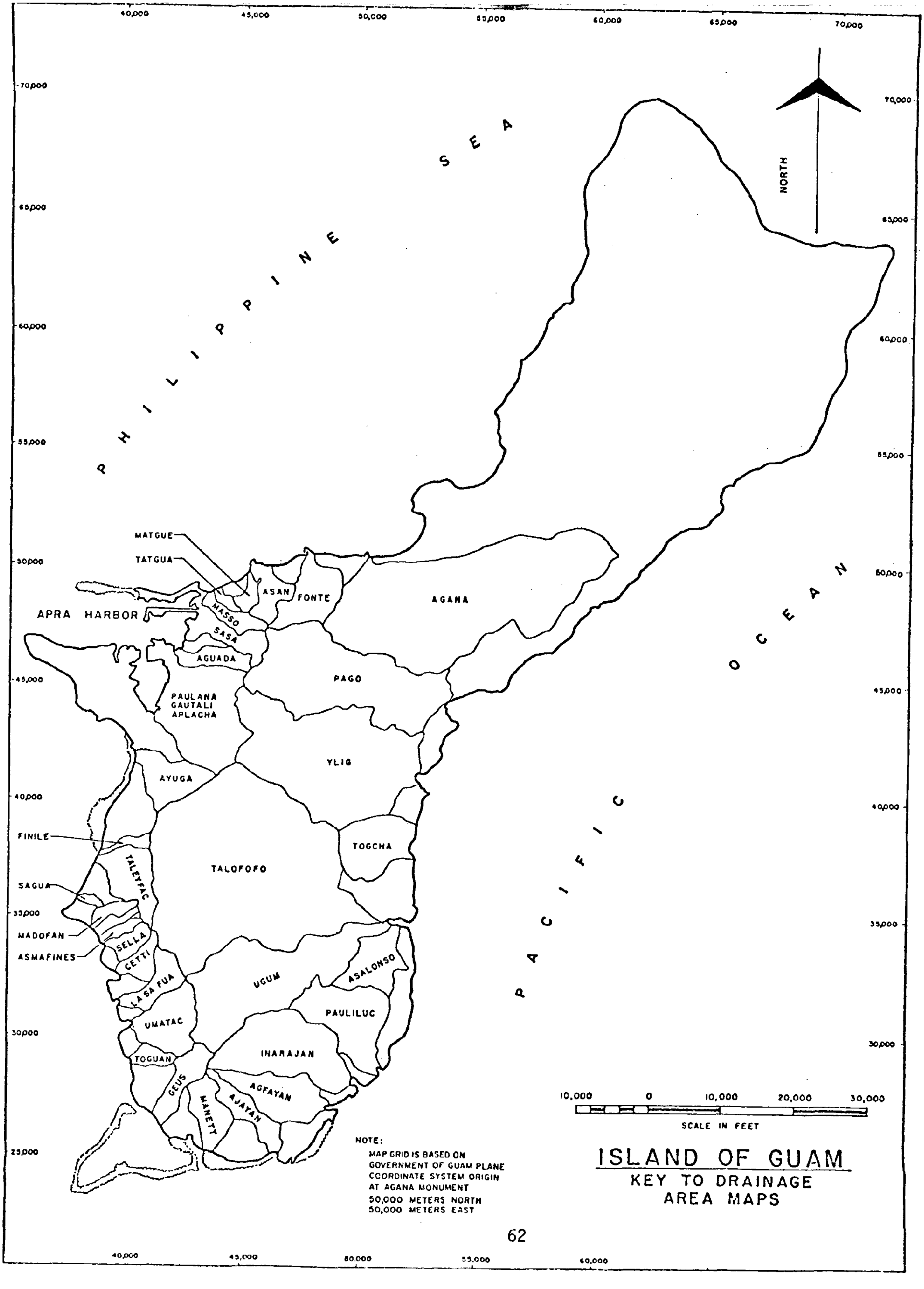
4. Ibid.

5. Ibid.

6. Ibid.

7. Ibid.

Chapter IV



PHILIPPINE SEA
PACIFIC OCEAN
NORTH
APRA HARBOR
MATGUE
TATGUA
ASAN
FONTE
AGANA
MASSO
SASA
AGUADA
PAGO
PAULANA
GAUTALI
APLACHA
YLIG
AYUGA
FINILE
TALEYFAC
TALOFOFO
TOGCHA
SAGUA
NADOFAN
ASMAFINES
SELLA
CETTI
LASA FUA
UGUM
ASALONSO
PAULILUC
UMATAC
TOGUAN
GEUS
MANETT
AJAYAN
AGFAYAN
INARAJAN
10,000 0 10,000 20,000 30,000
SCALE IN FEET
NOTE:
MAP GRID IS BASED ON
GOVERNMENT OF GUAM PLANE
COORDINATE SYSTEM ORIGIN
AT AGANA MONUMENT
50,000 METERS NORTH
50,000 METERS EAST
ISLAND OF GUAM
KEY TO DRAINAGE
AREA MAPS

IV. THE RIVERS

Thirty-two major drainage basins have been studied in this hydroelectric generation feasibility study. Thirty-one drainage area maps are included in this report. The Agana Swamp drainage area was omitted because the basin is predominantly limestone, and the water produced there is considered ground water. The Agana Springs are discussed, and are the only water source in this drainage area worthy of discussion relative to hydro development.[1]

The tabulation order begins at Orote Point going northward, through the central area of Guam, southward along the east coastline, around the southern tip and then northward again to Orote Point.[2]

Of the thirty-one drainage areas addressed, two have been studied for major impoundment projects. Although all the drainage areas will be discussed, attention will be focussed on those areas considered to be developable as surface water resources. This decision is based on the fact that the major expense in hydro development are the civil works - roads, dams, piping, etc. With the exception of the Fena dam, no existing impoundment area holds enough water too last through any significant dry period while discharging water to hydro applications. Consequently, any new development other than for individual or small farm use should marry the hydro plant to the fresh water production plant.

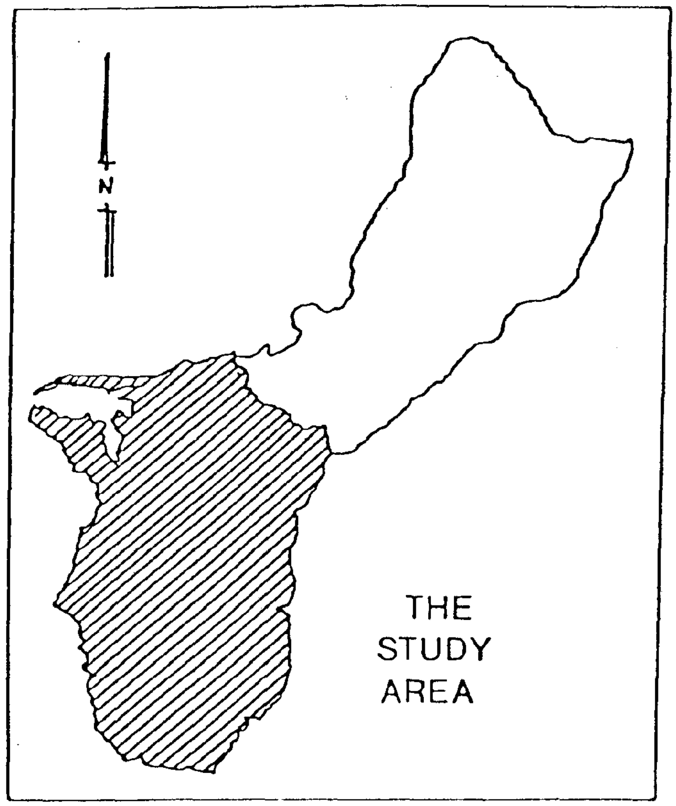
Ten drainage basins have been studied for surface water supply and these will be the first priority group to be addressed for hydro applications. Those that remain are characterized as being either too small, too inaccessable, or are normally dry during low rainfall months.

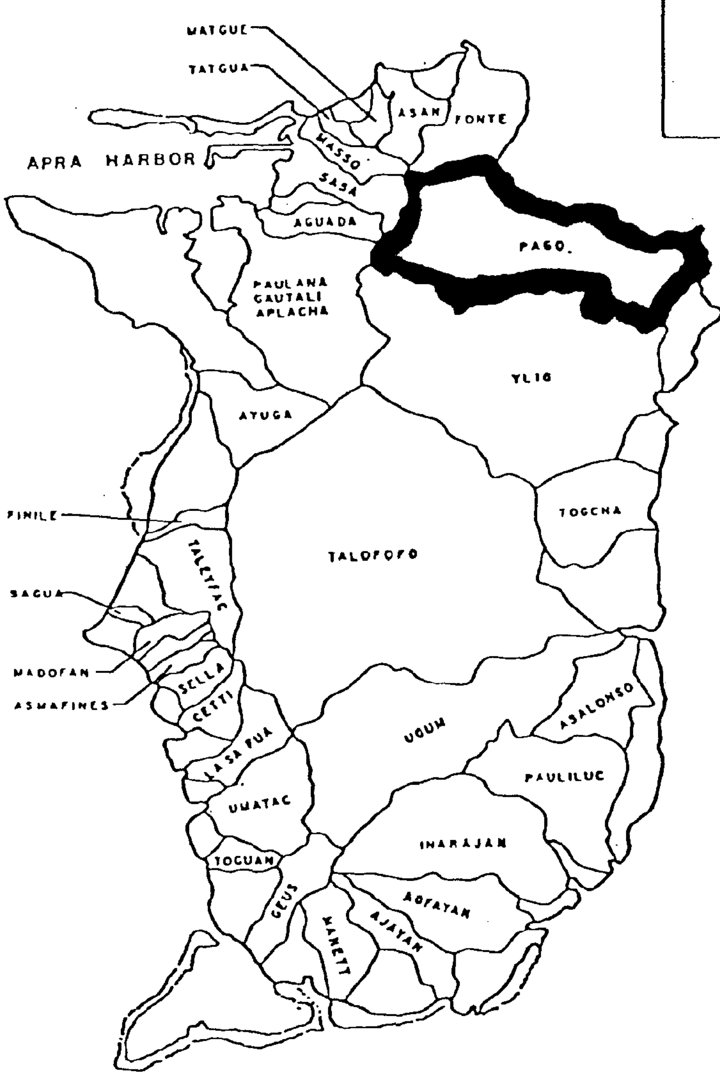
The ten major drainage basins are accompanied by duration-discharge curves which show "normal" and "dry" curves. The "normal" curve is based on the full record of the stream, while the "dry" curve shows the daily flow for only the year during which the stream flows were shown to be the lowest.[3]

A. <u>Pago River</u>

Drainage area = 9.0 sq.mi

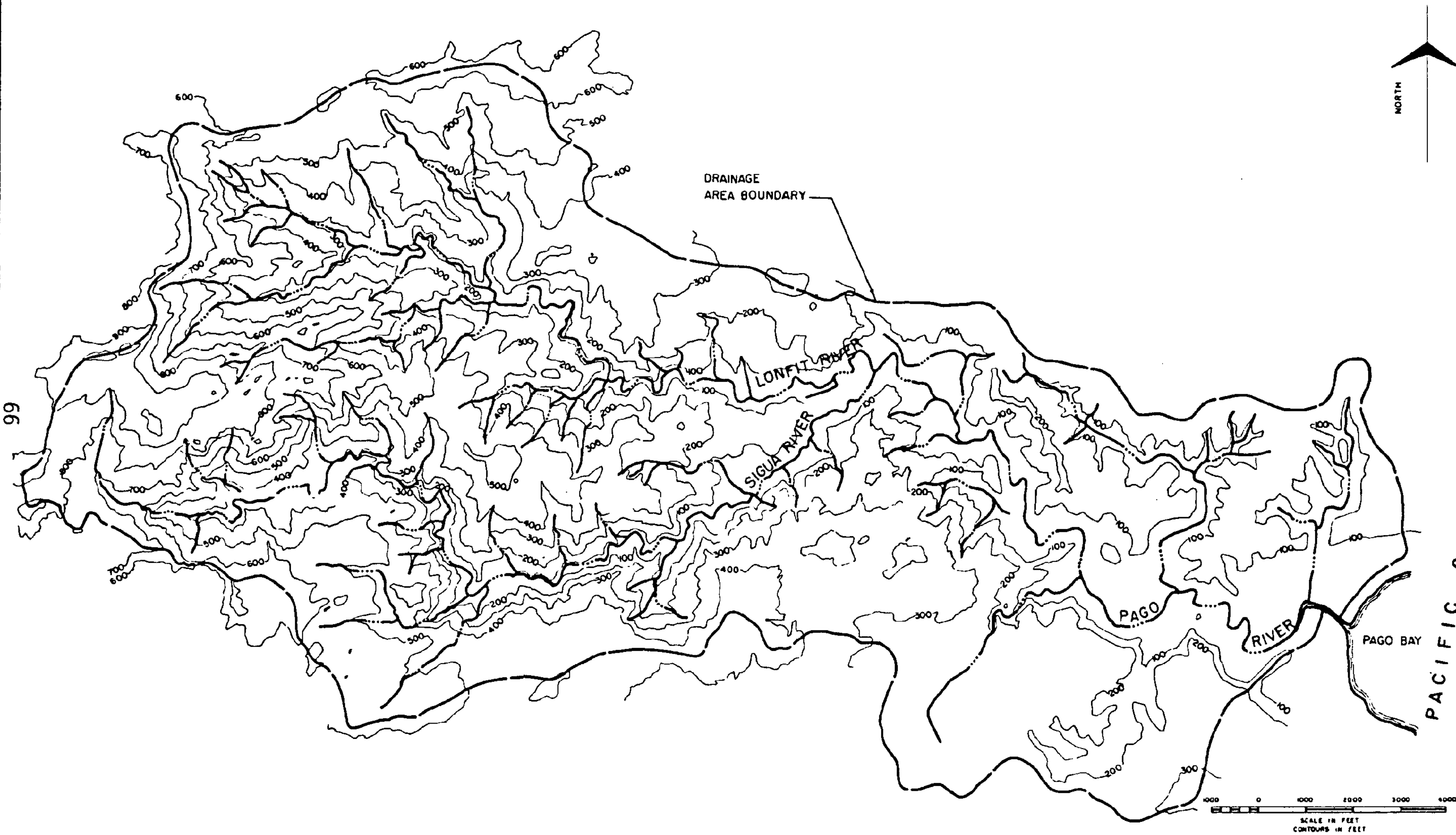
Located in the northeastern section of the study area, the Pago River drainage area is comprised of the main Pago River and its two principal branches, the Lonfit and Sigua Rivers. The confluence of the two rivers is located about 2.5 miles upstream of the mouth of Pago Bay, and join to form the Pago River at that intersection.[4]





<u>Geo-physical Notes for Pago River Basin</u>

Upper reaches - mountainous to rolling terrain underlain by deeply weathered volcanic rock.
North slope - comprised of permeable limestone.
South slope - lies in volcanic rock. Below the confluence of the Sigua and Lonfit, the stream channel is in a valley flat which is underlain by alluvium.
Point of discharge: Pago Bay, east coast of Guam.[5]



PAGO DRAINAGE SYSTEM

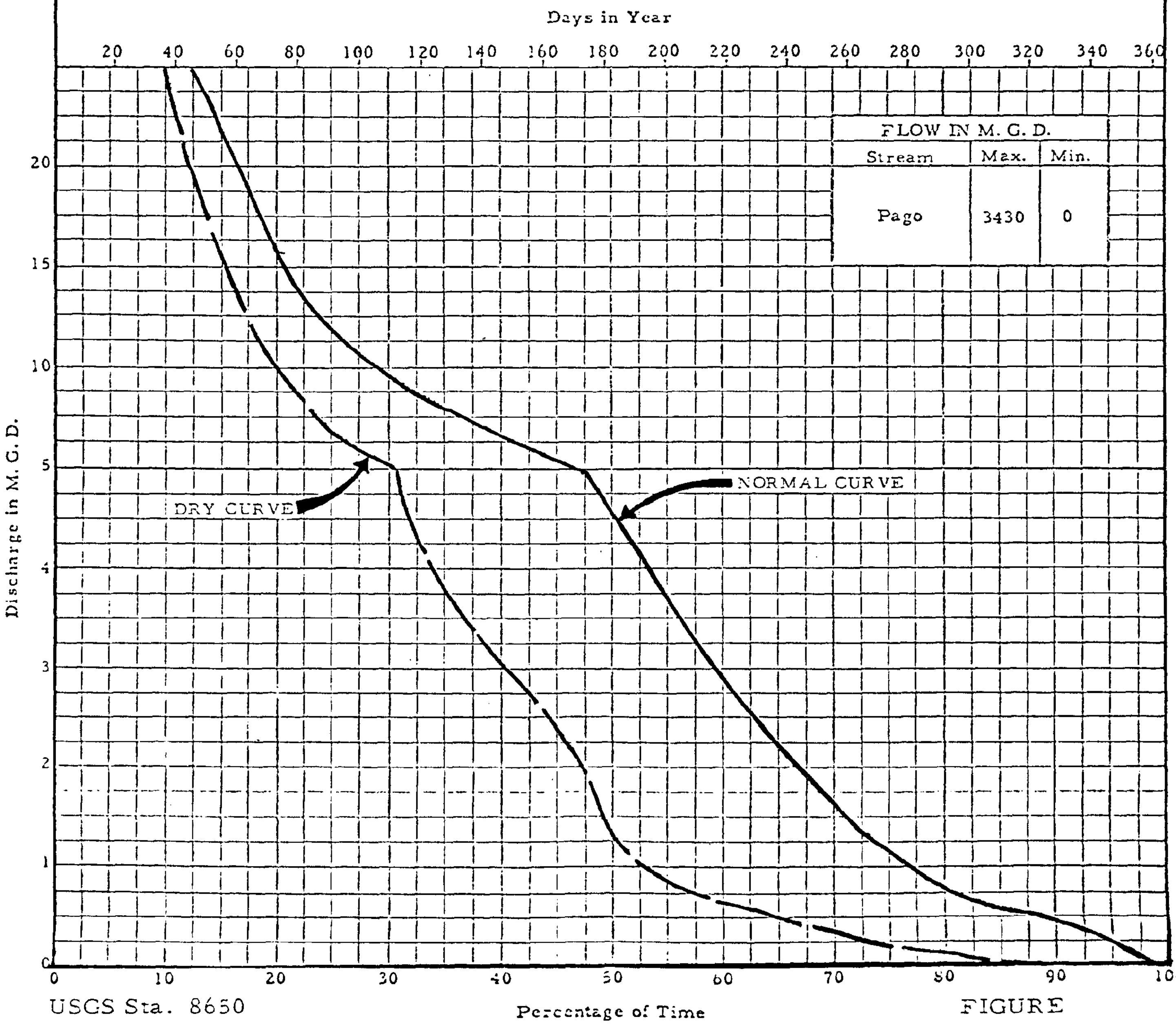
DURATION DISCHARGE CURVE

PAGO RIVER NEAR ORDOT

Record - 15 Years
1951 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5756 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	733	1203	1710	2206	2739	3423	3824	4085	4419	4850	5209	5546	5630	5756
No. of days in Dry Yr.*	37	57	73	93	112	148	173	180	192	220	247	268	290	365
Percentage of time	10.1	15.6	20.0	25.5	30.7	40.5	47.4	49.3	52.6	60.3	67.7	73.4	79.4	100
No. of days in Av. Yr.	46.5	76.3	108.4	139.9	173.7	217.1	242.5	259.0	280.2	307.6	330.3	361.7	357.0	365
Percentage of time	12.7	20.9	29.7	38.3	47.6	59.5	66.4	71.0	76.8	84.3	90.5	96.3	97.8	100

*Fiscal Year 65-66



USGS Sta. 8650
Elevation 25'±

FIGURE

DURATION DISCHARGE CURVE

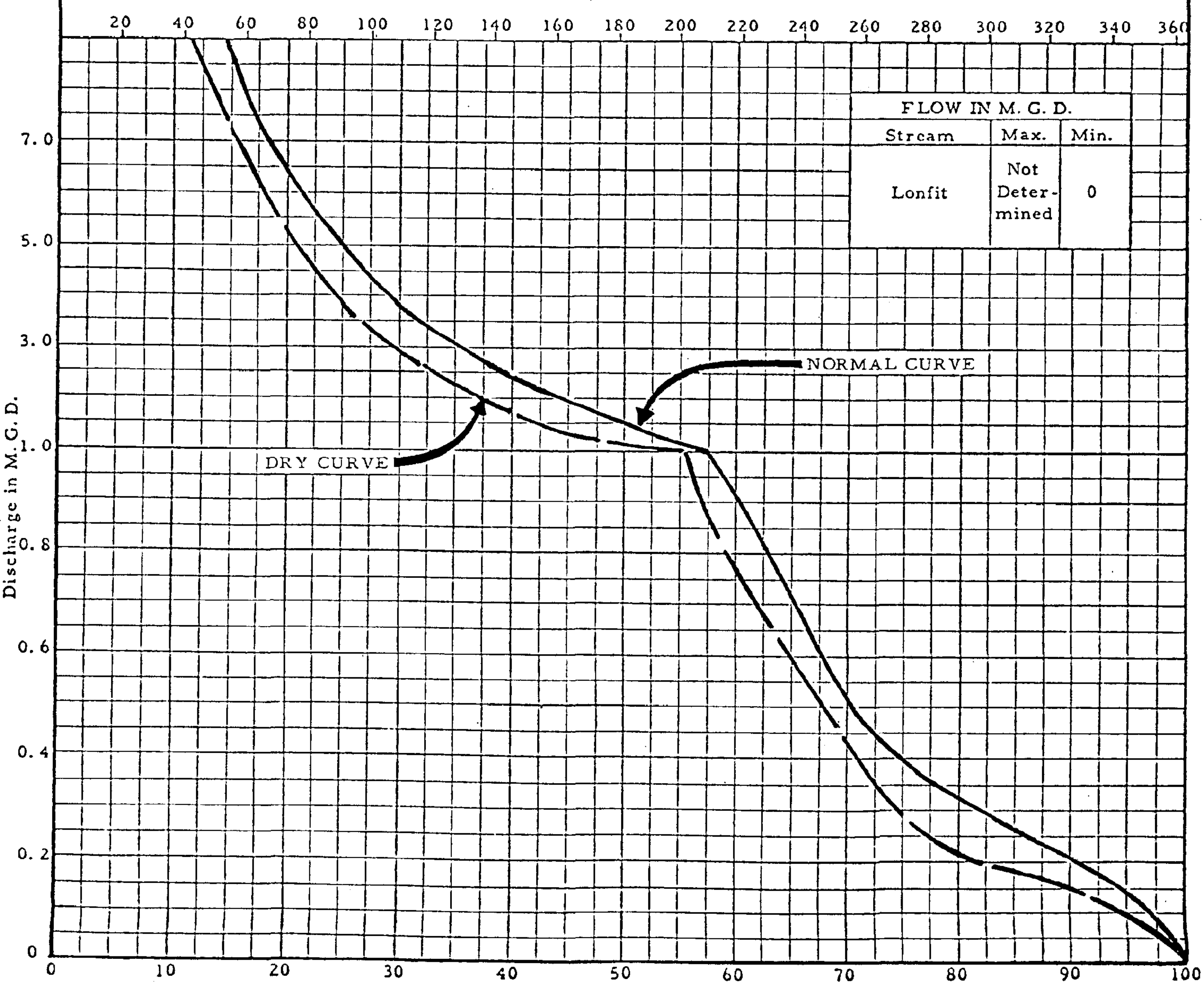
LONFIT RIVER NEAR ORDOT

Record - 8 Years
1951 - 1960

Discontinued Mar. 31, 1960

Period of Record 3110 Days	Discharge Equal to or Exceeding - in M. G. D.													
	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	163	264	407	580	761	1104	1383	1554	1783	2089	2309	2767	3019	3110
No. of days in Dry Yr.*	15	26	42	57	78	105	138	152	202	236	258	294	343	365
Percentage of time	4.1	7.1	11.5	15.6	21.4	28.8	37.8	41.6	55.3	64.7	70.7	80.5	94.0	100
No. of days in Av. Yr.	19.1	31.0	47.8	68.1	89.3	129.5	162.3	182.4	209.3	245.2	271.0	324.8	354.3	365
Percentage of time	5.2	8.5	13.1	18.6	24.5	35.5	44.5	50.0	57.3	67.2	74.2	89.0	97.1	100

*Fiscal Year 57-58



USGS Sta. 8620
Elevation 30'±

Percentage of Time

FIGURE

Measurements. The flow duration curves and data are shown on figures 4-3 and 4-4. These measurement records show that the flows vary from 3,430 mgd to 0, for a period of record of 5,756 days.[6]

The average flow recorded at guaging station #8560 is 16.6 mgd. 90% of the time the flow is .45 mgd. This is measured at guaging station #8650, which is 3.22 miles from the estuary. There are two head waters located 5.65 miles inland on the Lonfit River and 5.8 miles inland on the Sigua River.[7]

For 75 days, during the drought year of 1965 to 1966, the Pago River flowed less than .1 mgd. For 49 days in this period, 45 of which were continuous, there was no flow at all.[8]

Power/head characteristics. Approximately 60% of the main bodies of the Pago River flow is at an elevation of less than 100 feet. The remaining sections climb to an altitude of 800+ feet where the streams originate.

The elevation at guaging station #8560 is 25 feet. This section of the River continues downstream at a gradual fall. Consequently, any head that could be developed over, say, 10 feet, would have to be created artificially by damming. The most promising head/flow combinations are found from .5 miles upstream of the headwater locations on both the Sigua and Lonfit down to the gauging station. On both rivers the headwater location lies approximately halfway between the 200' and 100' contours.

The theoretical instantaneous power potential at the headwater location, assuming a 25 foot head, a plant efficiency of 80%, and flow by the headwater definition (5 CFS) is 11.34 kW.

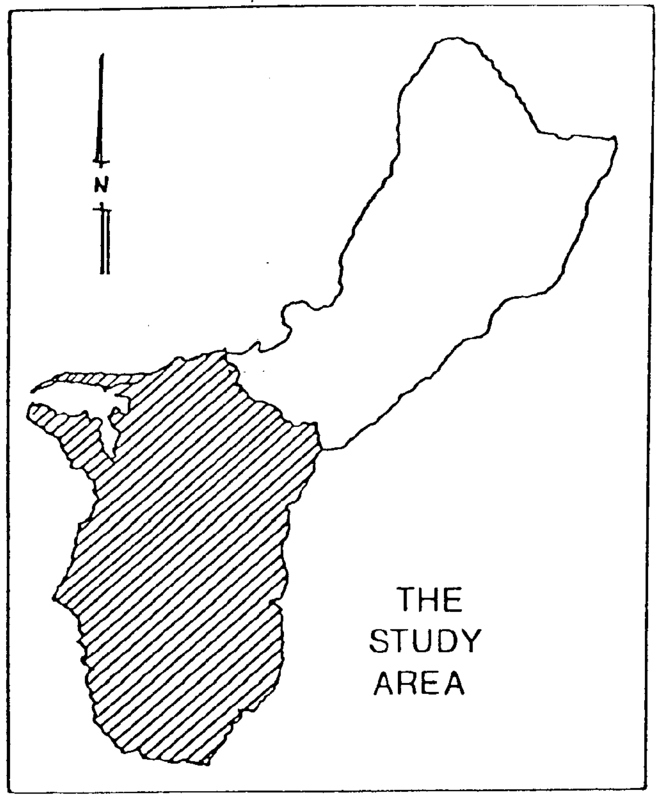
The theoretical instantaneous power potential at the guaging station, assuming the same plant efficiency, head of 10 ft and the average flow of the river (25.69 CFS) is 23.3 kW.

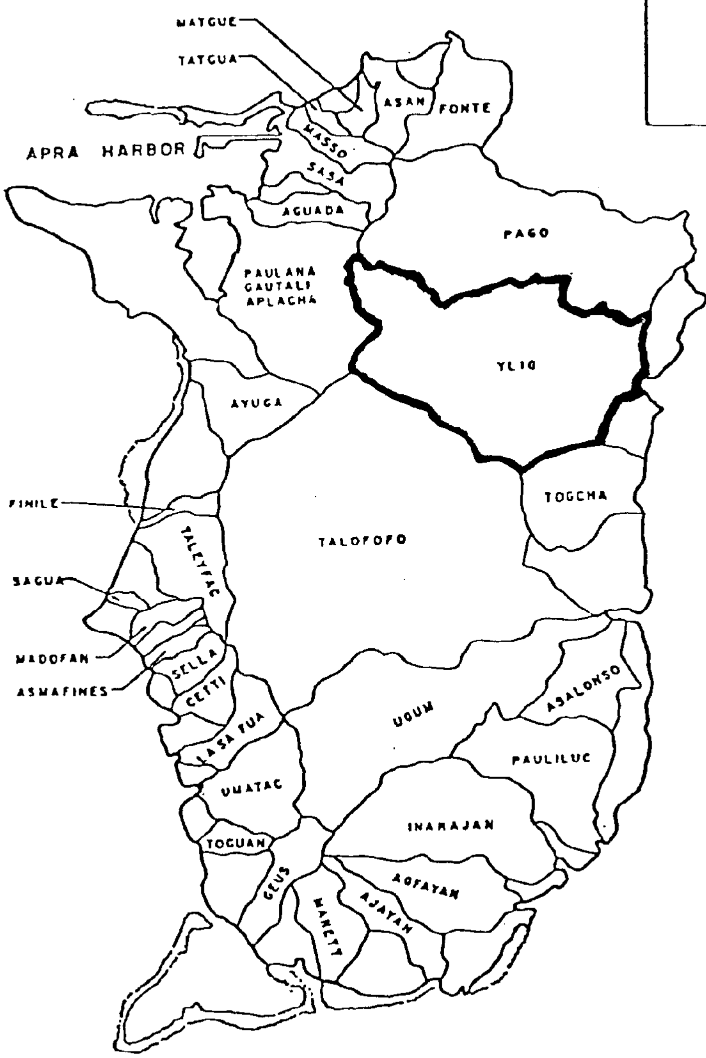
Assuming the same efficiency and head and assuming flow to be equal to the 90% case (.7 CFS), the instananeous theoretical power potential is 630 watts. This disparity shows the impact of the low flow and no flow periods. Because of these periods, installations of around 10 kW would have to be tied into the Guam Power Authority electrical system to assure year-round power. This is, incidentally, the usual case on Guam. Records indicate that all of the guaged rivers have 90% cases which are quantitatively a fraction of the average flow cases.

B. Ylig River

Drainage Area = 11.6 sq mi

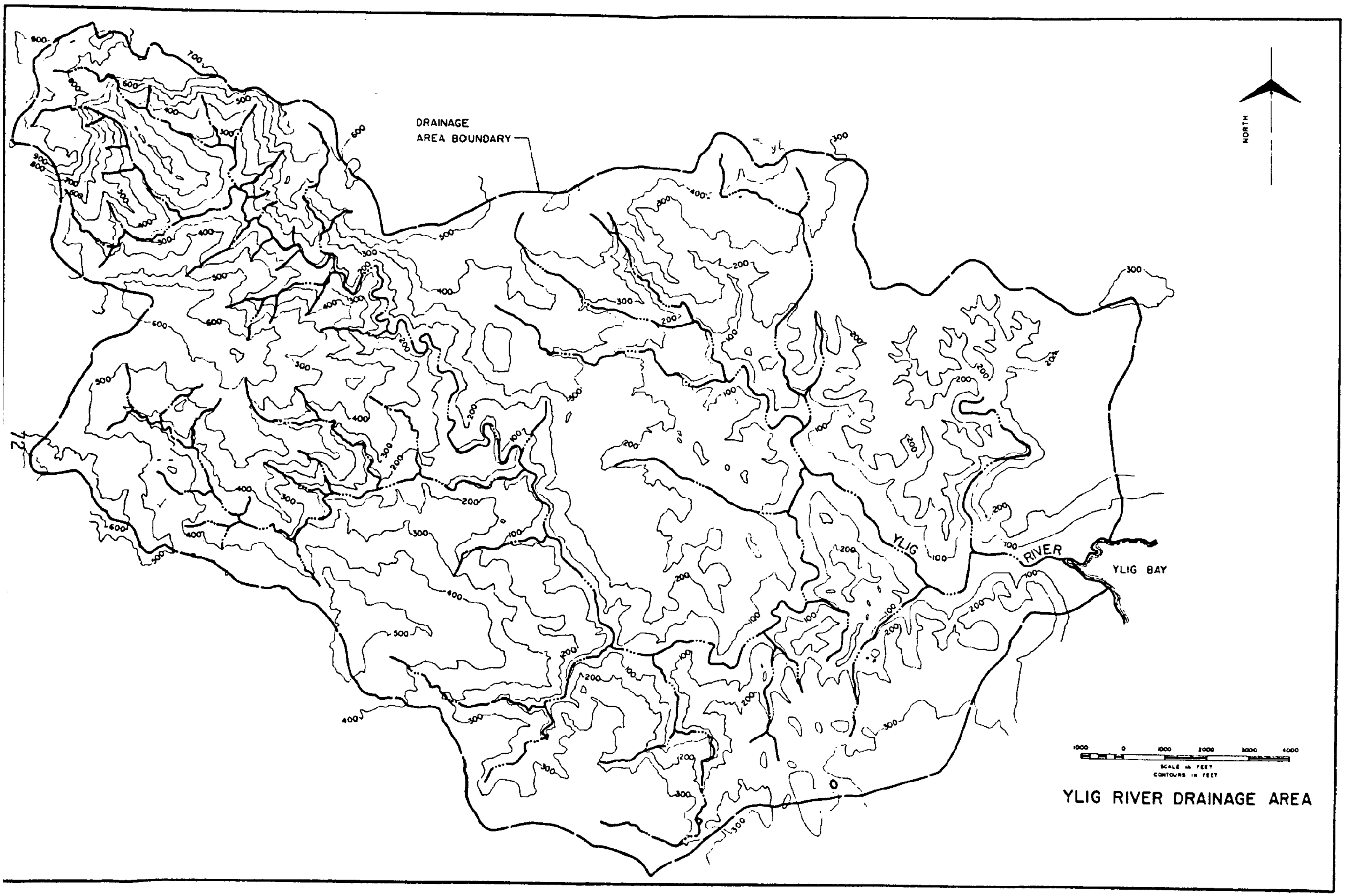
The Ylig basin is located just south of the Pago River basin and is formed by numerous tributaries including the Tarzan River and the Manengon River. The Ylig River basin, approx. 5 miles long and 3 miles wide at its broadest point, is the main source of water for the village of Yona, which collects the water from below the gauging station.[9]





Geo-physical notes for the Ylig River basin

Upper reaches, main stream and several tributaries - flows on highly weathered rock at steep gradient.
Lower reaches - deep valley cut across narrow limestone plateau.
Point of discharge - Ylig Bay, east coast of Guam.[10]



YLIG RIVER DRAINAGE AREA

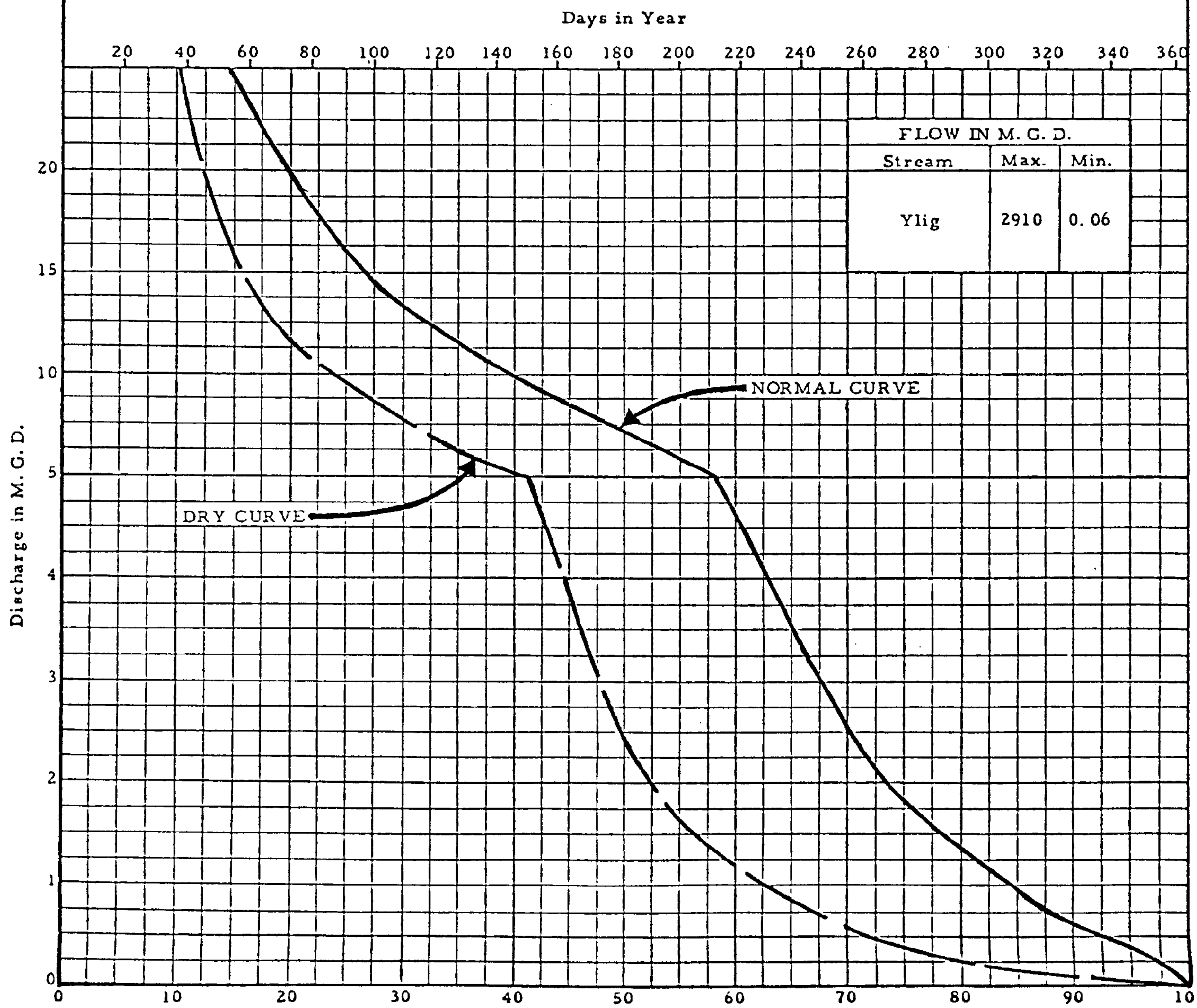
DURATION DISCHARGE CURVE

YLIG RIVER NEAR YONA

Record - 15 Years
1952 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5492 Days	25	15	10	7	5	3	2	1. 5	1. 0	0. 6	0. 4	0. 2	0. 1	0. 0
(Partial Years Included)	810	1469	2183	2777	3194	3710	4038	4293	4643	4973	5205	5396	5451	5492
No. of days in Dry Yr.*	37	58	89	118	152	174	192	205	227	254	271	299	324	365
Percentage of time	10. 1	15. 9	24. 4	32. 3	41. 6	47. 7	52. 6	56. 2	62. 2	69. 6	74. 2	81. 9	88. 8	100
No. of days in Av. Yr.	53. 8	97. 6	145. 1	184. 6	212. 3	246. 6	268. 4	285. 3	308. 6	330. 5	345. 9	358. 6	362. 3	365
Percentage of time	14. 7	26. 7	39. 7	50. 6	58. 2	67. 5	73. 5	78. 2	84. 5	90. 5	94. 8	98. 2	99. 2	100

*Fiscal Year 65-66



USGS Sta. 8580
Elevation 60'±

Percentage of Time

FIGURE

Measurements. The flow duration curves and data are shown on figure 4-6. These measurements show that the flows vary from a maximum of 2,910 mgd to a minimum of .06 mgd, for a period of record of 5,492 days from 1952 to 1967. The average flow of the Ylig River, measured at guaging station #8580, is 18.7 mgd. 90% of the time, the flow on the river is .71 mgd.[11]

The Ylig has three head water locations: one on the Ylig, 7.45 miles upstream, one on the Tarzan River 5.16 miles upstream, and one on the Manengon River, 3.94 miles upstream from Ylig Bay.

For 18.1% of the drought year of 1965-1966, the stream flow was less than .2 mgd. The flow on the Ylig falls below .4 mgd more often than 25% of the time during drought years.[12]

Power/head characteristics. Roughly half of the main bodies of the Ylig River flow at of elevations less than 100 feet. The remaining sections flow at elevations up to 300 to 400 feet for the bulk of the drainage area. The Ylig mainstream extends well up into the highlands in one section to elevations of 900+ feet where it originates.

The elevation at guaging station #8580 is 60 ft. Located on the this lower reach, the section from the guaging station to the estuary, has a low gradient. Consequently, any head that could be developed over 20 feet would have to be artifically created by a dam. This could prove impractical because this section of the river runs across a highly permeable limestone plateau and the leakage would be high.

In the upper reaches where the dense underground rock would permit damming, the steep gradients prohibit large impoundments. The head/flow combinations are adequate to support a smaller scale hydro site (10 kW) for agricultural puposes, provided the farm owner could locate a suitable impoundment area. It should be noted that the bulk of the Ylig is zoned conservation and only a small section of the Central Ylig is zoned agricultural.

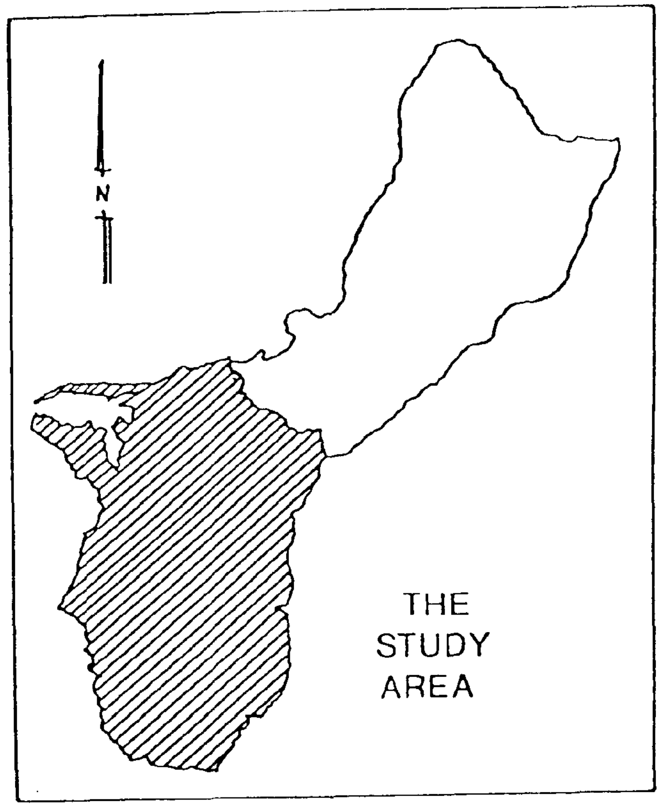
As in the Pago case, the Ylig has periods in excess of two months that yield inadequate amounts of water for substantial hydro generation. At the guaging stations, assuming a head of 15 feet, a plant efficiency of 80%, and using the 90% flow case (.71 CFS) the intantaneous theoretical power potential would be .91 kW. At the same site, with the same head and efficiency assumptions, the flow-duration curves indicate that 15 kW of power could be available about 50% of the time in the "normal year". With the same assumptions, the average flow would yield about 39.37 kW, which corresponds to the 22% case.

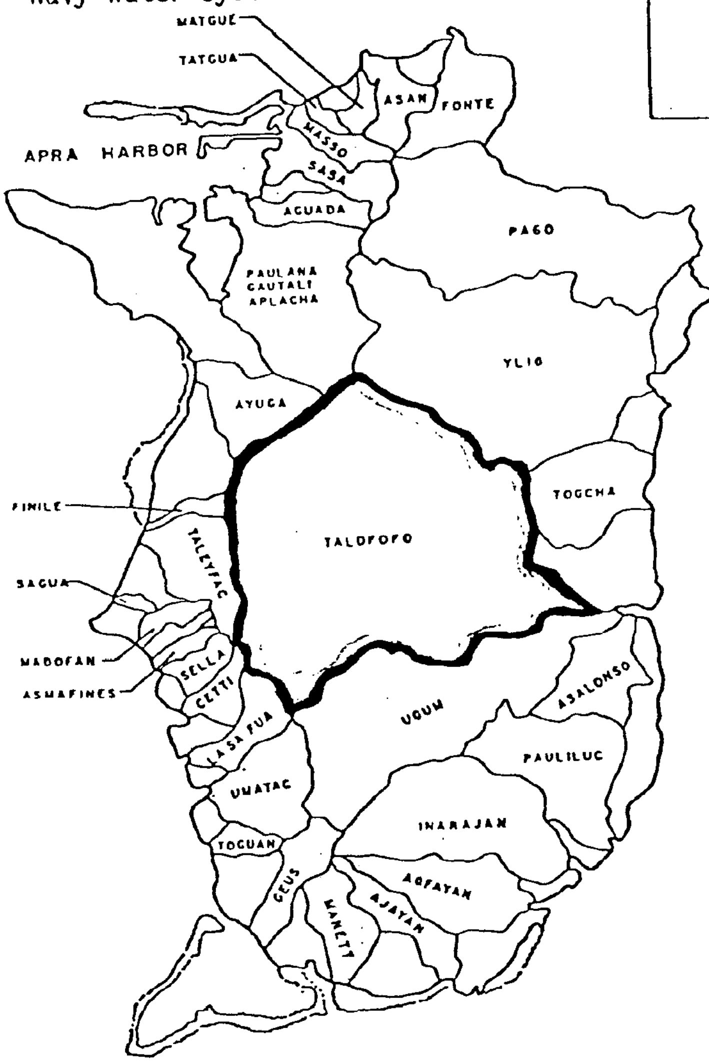
At the headwater locations, particularly the Ylig mainstream headwater, much higher heads (50-70 ft.) are available, but access and impoundment potential are more limited. Although 20 - 35 kW could theoretically be developed, using hardware such as a "Pelton" plant, that could utilize 50 to 75 feet of head at low average flows (5 CFS) to develop that amount of power.

C. Talofofo River

Drainage area = 20.8 sq mi

The Talofofo River basin lies south of the Ylig River basin and is the largest river basin on Guam. The Talofofo River is that stretch below the confluence of the Maagas and Mahlac Rivers, two of the many tributaries that feet the Talofofo including the Talisay, Bonya, Maemong, Talifac, Maulap, Almagosa, Imong, Tinechong, Sagge, and Sarasa Rivers. A dam contructed across the valley above the confluence of the Maaga and Tolaeyuus (Lost River) forms the Fena Valley Reservoir which supplies the Navy water system.[13]





Geo-physical notes for the Talofofo River basin.

General - The main Talofofo River valley floor and the larger tributaries are underlaid by alluvium.

River basin - underlain largely by volcanic rocks and noncalcareous sediments which are deeply weathered.

Northern side - Upper tributaries, the Talisay, Bonya, Maemong, and Tolaeyuus Rivers, flow across limestone terrain. Sections of the Maemong and Tolaeyuus flow underground in a limestone cavern.

West side - Limestone caps occur on hills on west side of basin forming numerous springs. The Almagosa Spring is one which is of major importance.

Point of drainage - Talofofo Bay, east coast of Guam.[14]

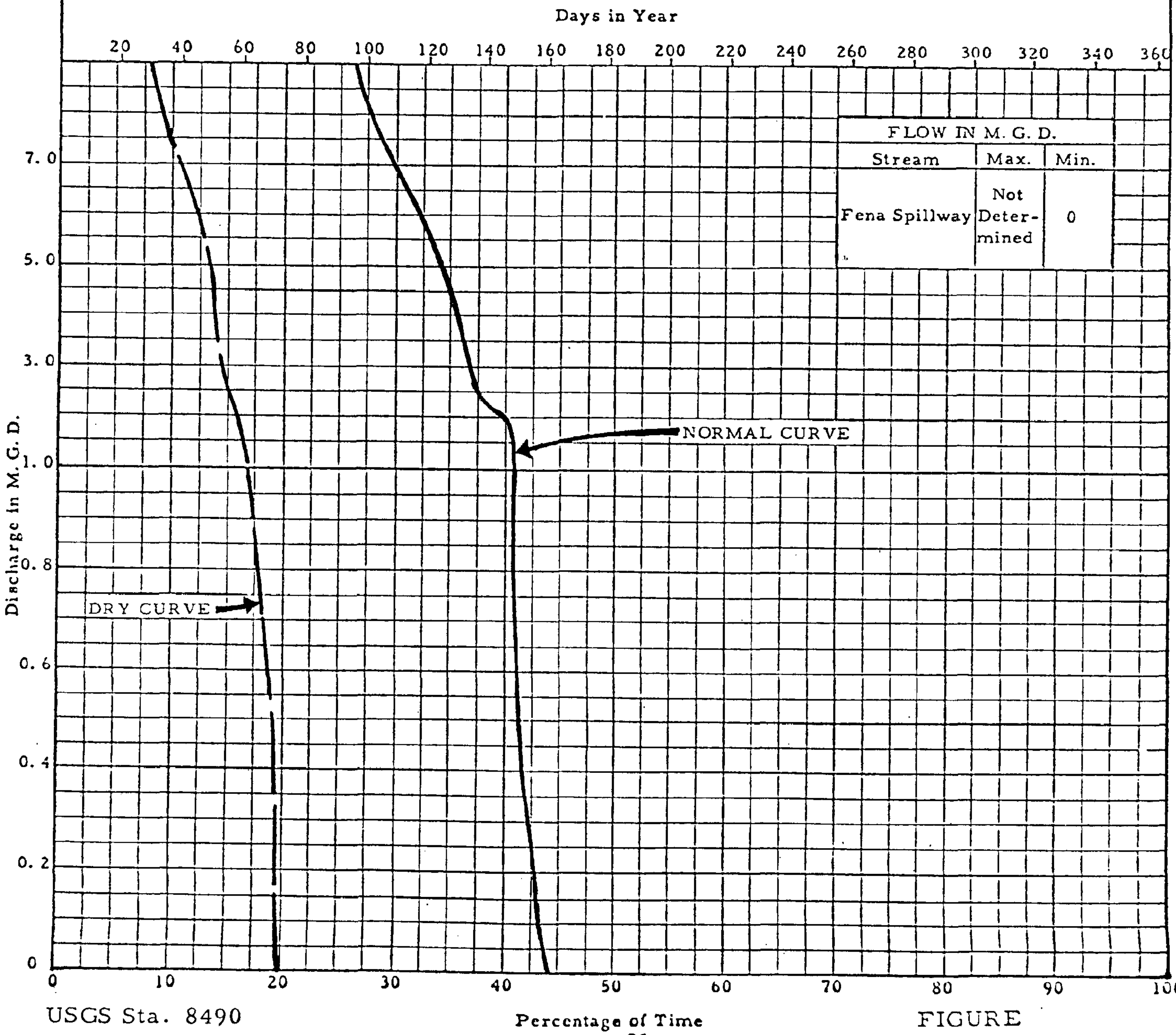
DURATION DISCHARGE CURVE

FENA DAM SPILLWAY NEAR AGAT

Record - 15 Years
1951 - 1967

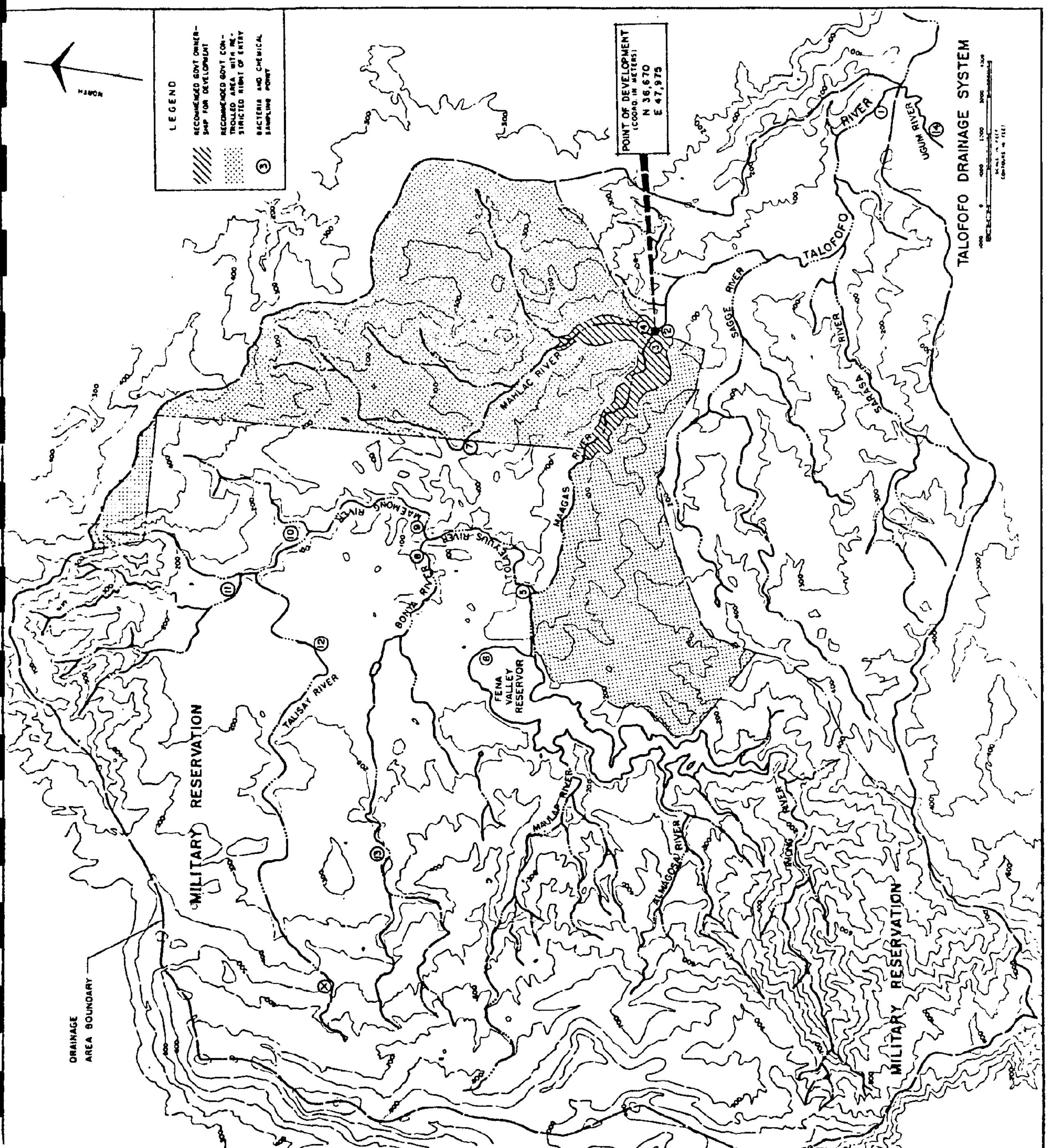
Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5651 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	637	1052	1420	1718	1976	2084	2175	2269	2273	2352	2358	2429	2434	5651
No. of days in Dry Yr.*	11	16	30	38	50	54	56	61	61	69	69	70	70	366
Percentage of time	3.0	4.4	8.2	10.4	13.7	14.8	15.3	16.7	16.7	18.9	18.9	19.1	19.1	100
No. of days in Av. Yr.	41	68	92	111	128	135	141	147	147	152	152	157	157	365
Percentage of time	11.2	18.6	25.2	30.4	35.1	37.0	38.6	40.3	40.3	41.6	41.6	43.0	43.0	100

*Fiscal Year 59-60



USGS Sta. 8490
Elevation 111'

FIGURE


TALOFOFO DRAINAGE SYSTEM
LEGEND
RECOMMENDED GOVT OWNERSHIP FOR DEVELOPMENT
RECOMMENDED GOVT CONTROLLED AREA WITH RESTRICTED RIGHT OF ENTRY
BACTERIA AND CHEMICAL SAMPLING POINT
POINT OF DEVELOPMENT
(COORD. IN METERS)
N 36,670
E 47,975
NORTH
DRAINAGE AREA BOUNDARY
MILITARY RESERVATION
MILITARY RESERVATION
UGUM RIVER
TALOFOFO RIVER
SAGGE RIVER
SARASA RIVER
MAHLAC RIVER
HAAGAS RIVER
MAEMONG RIVER
BONYA RIVER
TALISAT RIVER
FENA VALLEY RESERVOIR
MAULAP RIVER
ALMAGOSA RIVER
IMONG RIVER

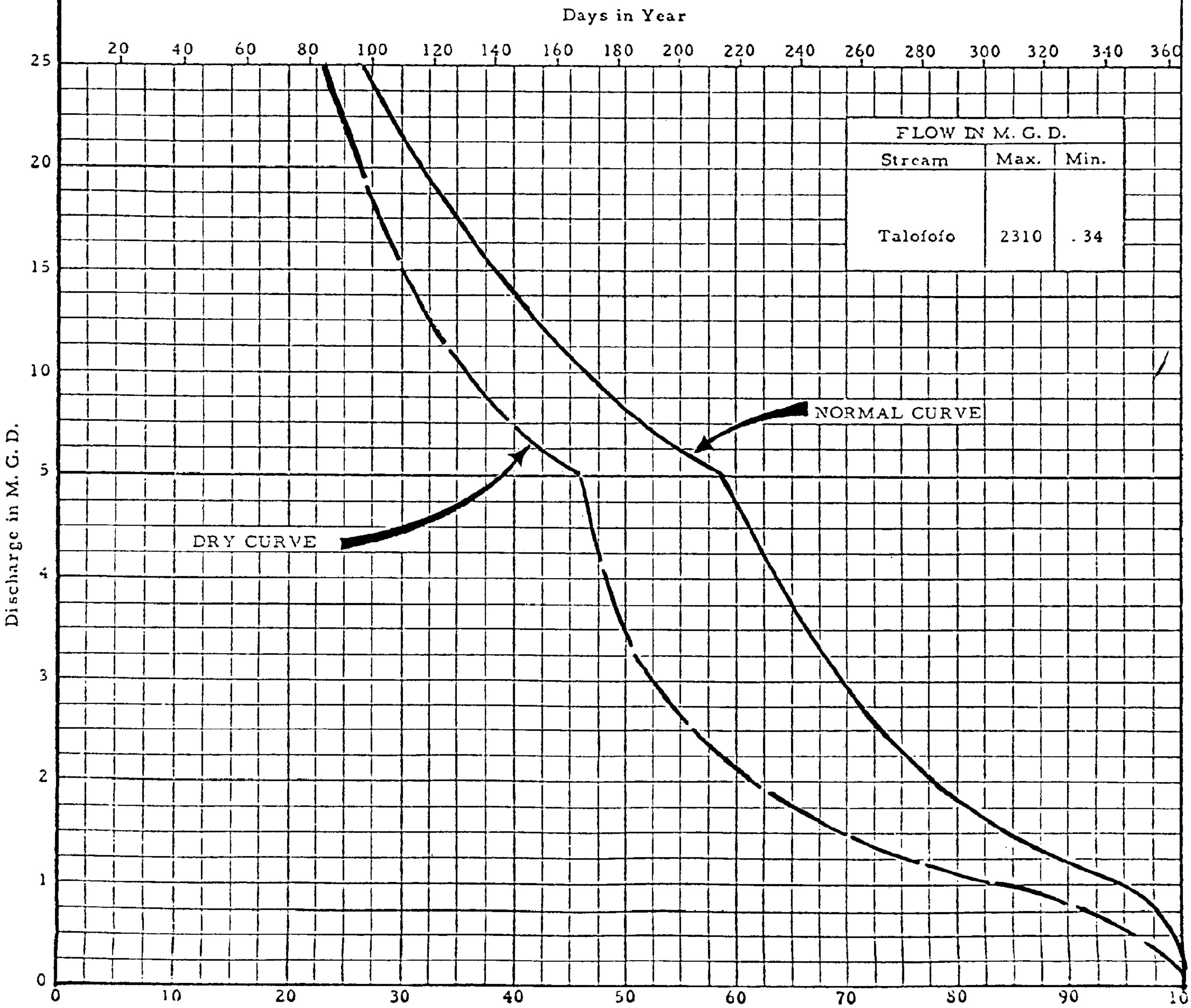
DURATION DISCHARGE CURVE

TALOFOFO (MAAGAS)

Record - 10 Years
1951 - 1962
Discontinued June 30, 1962

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
3881 Days	75	50	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2
(Partial Years Included)	326	554	1023	1487	1802	2014	2265	2703	3048	3290	3684	3832	3879	3881
No. of days in Dry Yr.*	17	31	84	111	125	153	168	192	234	255	306	348	366	366
Percentage of time	4.6	8.5	22.9	30.3	34.1	41.8	45.9	52.5	63.9	69.7	83.6	95.1	100	100
No. of days in Av. Yr.	30.7	52.1	96.2	139.8	169.5	189.4	213.0	254.2	286.6	309.4	346.5	360.4	364.8	365
Percentage of time	8.4	14.3	26.3	38.3	46.4	51.9	58.3	69.6	78.5	84.8	94.9	98.7	99.9	100

*Fiscal Year 59-60



USGS Sta. 8500
Elevation 20'±

FIGURE

DURATION DISCHARGE CURVE

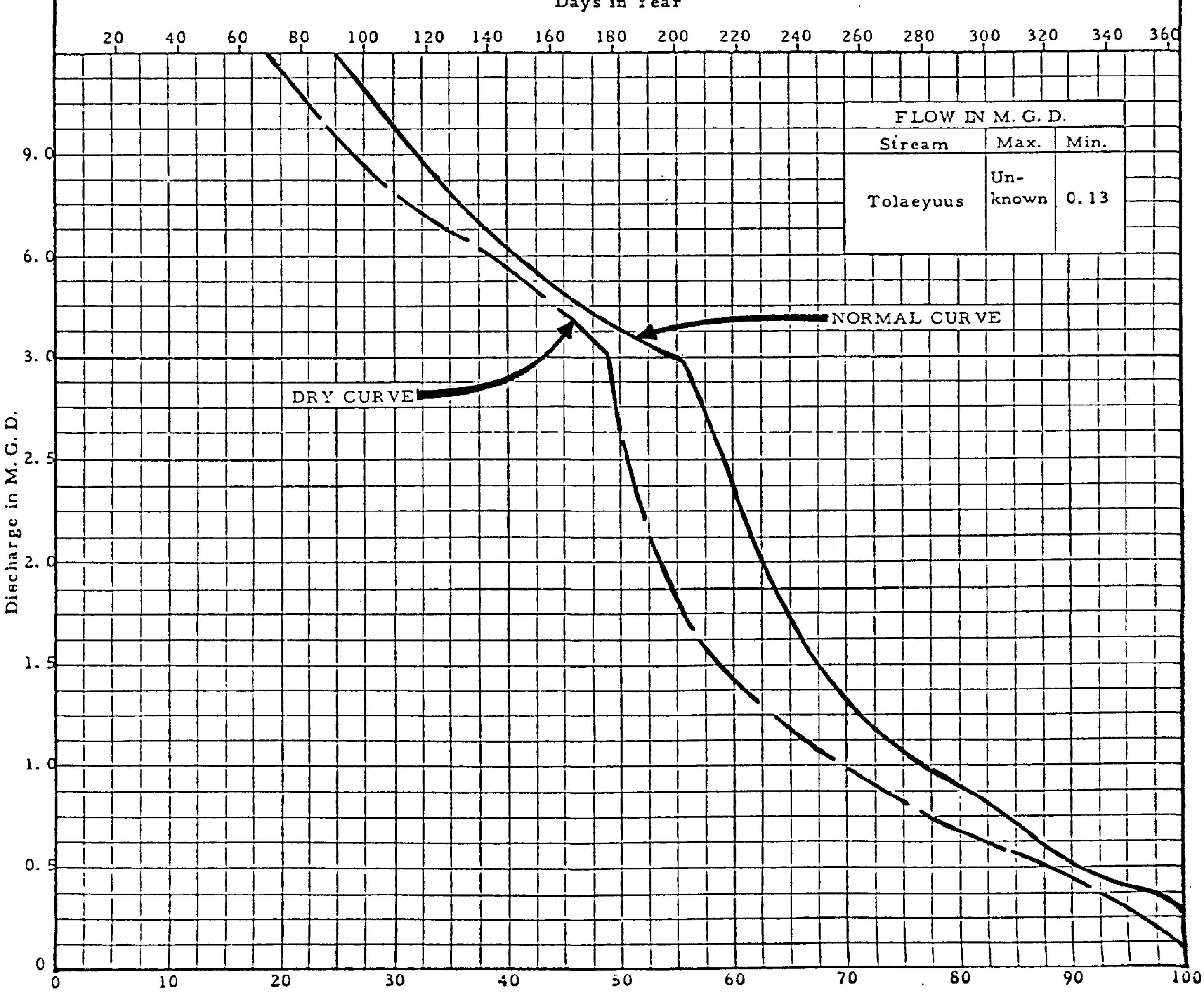
TOLAEYUUS RIVER NEAR AGAT

Record - 8 Years
1951 - 1960

Discontinued July 18, 1960

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
3217 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	374	664	951	1219	1449	1793	2025	2185	2482	2824	3058	3199	3217	3217
No. of days in Dry Yr.*	39	62	87	124	154	179	196	214	255	304	334	357	366	366
Percentage of time	10.7	16.9	23.8	33.9	42.1	49.0	53.7	58.5	69.7	83.1	91.2	97.5	100	100
No. of days in Av. Yr.	42.4	75.3	107.9	138.3	164.4	203.4	229.8	247.9	281.6	320.4	347.0	363	365	365
Percentage of time	11.6	20.6	29.6	37.9	45.0	55.7	62.9	67.9	77.1	87.8	95.1	99.4	100	100

*Fiscal Year 59-60



Percentage of Time

USGS Sta. 8450
Elevation 90'±

FIGURE

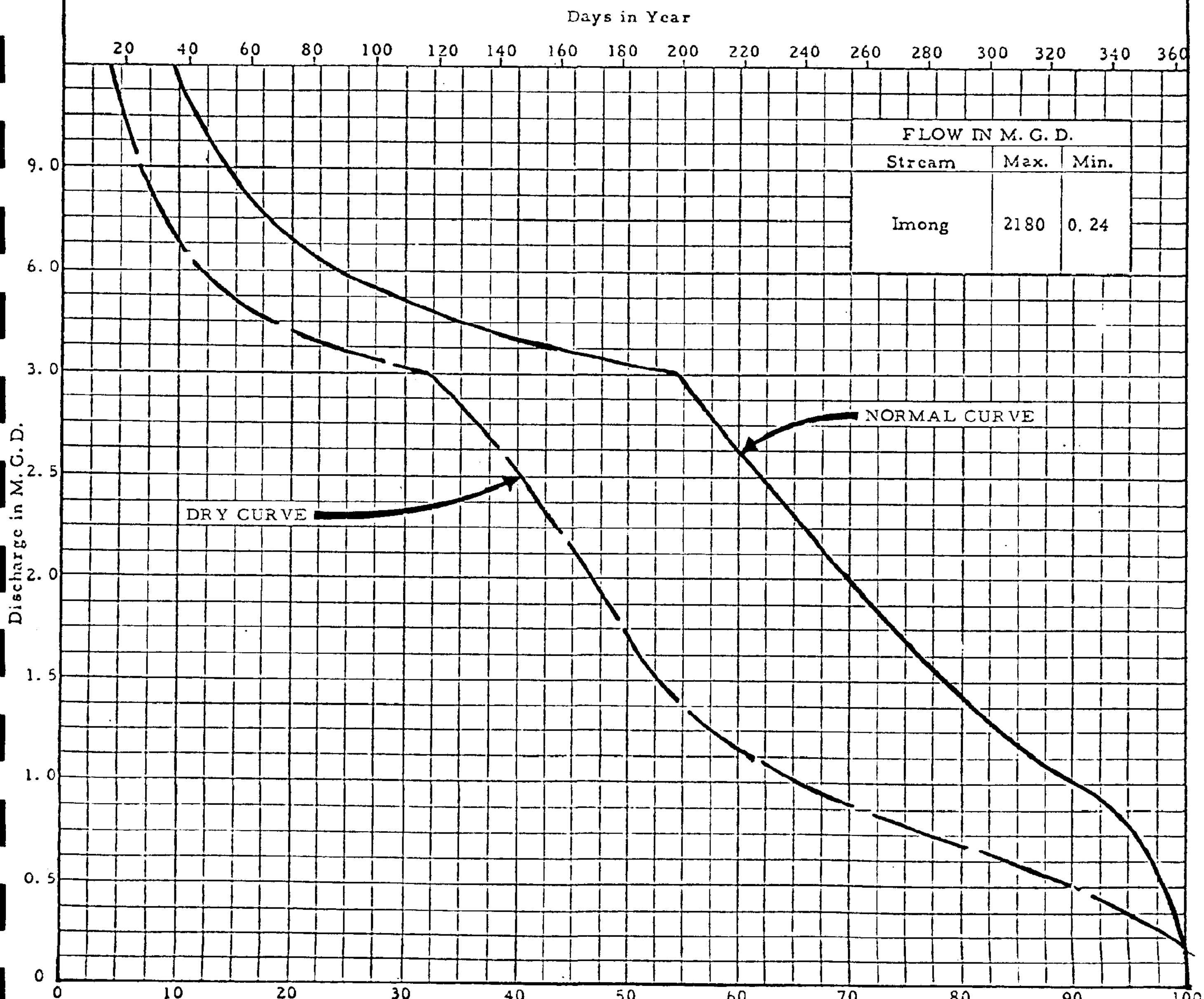
DURATION DISCHARGE CURVE

IMONG RIVER NEAR AGAT

Record - 6 Years
1960 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
2306 Days	25	15	10	7	5	3	2	1. 5	1. 0	0. 6	0. 4	0. 2	0. 1	0. 0
(Partial Years Included)	99	187	283	446	708	1251	1612	1818	2082	2253	2281	2306	2306	2306
No. of days in Dry Yr.*	6	12	21	35	58	117	171	192	238	312	340	365	365	365
Percentage of time	1. 6	3. 3	5. 7	9. 6	15. 9	32. 0	46. 8	52. 6	65. 2	85. 5	93. 1	100	100	100
No. of days in Av. Yr.	15. 7	295. 9	447. 8	705. 7	112. 1	197. 9	255. 1	287. 6	329. 4	356. 5	360. 9	365. 0	365. 0	365. 0
Percentage of time	4. 3	8. 1	12. 3	19. 3	30. 7	54. 2	69. 9	78. 8	90. 2	97. 7	98. 9	100	100	100

*Fiscal Year 65-66



USGS Sta. 8470
Elevation 120'±

Percentage of Time

FIGURE

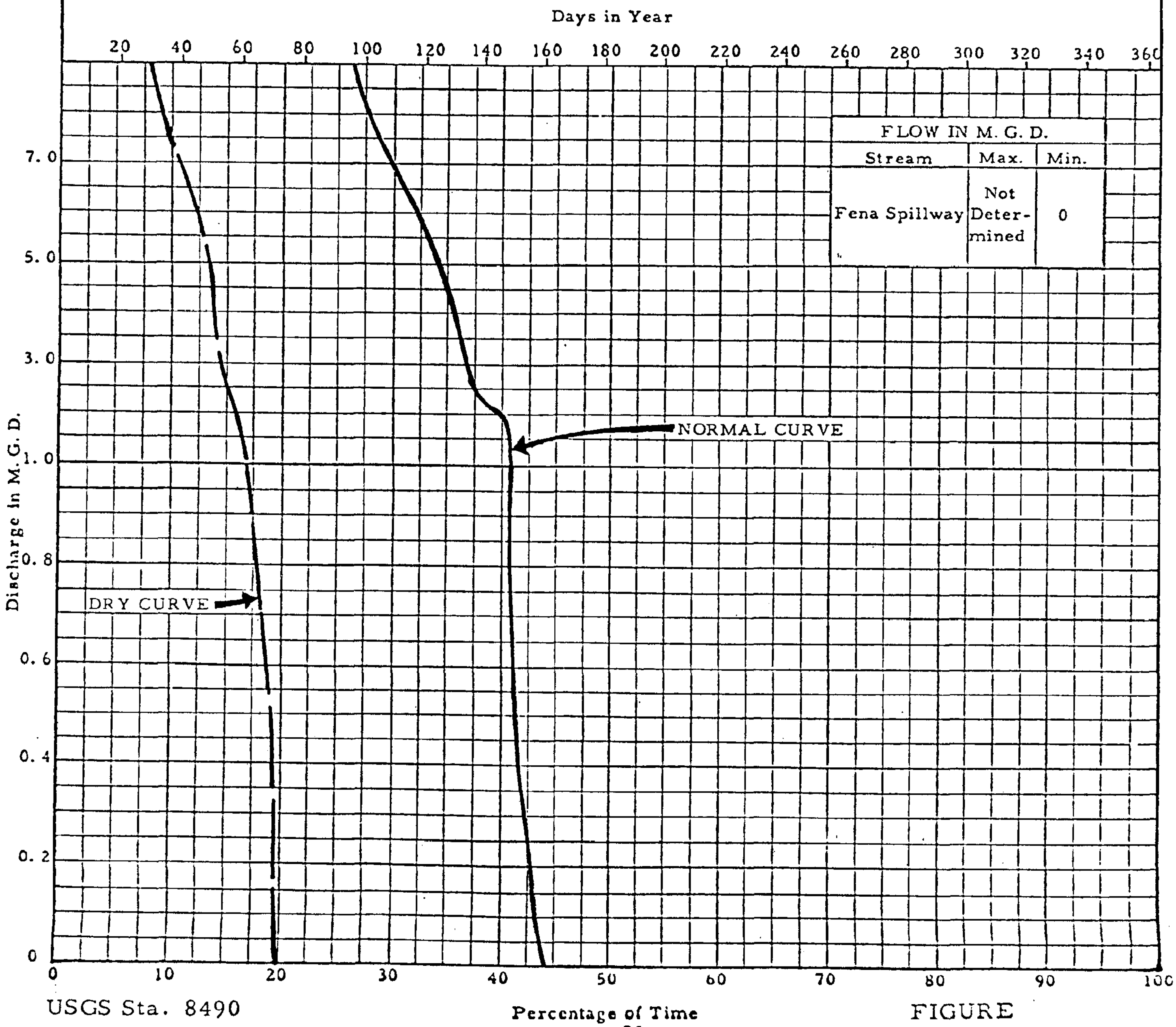
DURATION DISCHARGE CURVE

FENA DAM SPILLWAY NEAR AGAT

Record - 15 Years
1951 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5651 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	637	1052	1420	1718	1976	2084	2175	2269	2273	2352	2358	2429	2434	5651
No. of days in Dry Yr.*	11	16	30	38	50	54	56	61	61	69	69	70	70	366
Percentage of time	3.0	4.4	8.2	10.4	13.7	14.8	15.3	16.7	16.7	18.9	18.9	19.1	19.1	100
No. of days in Av. Yr.	41	68	92	111	128	135	141	147	147	152	152	157	157	365
Percentage of time	11.2	18.6	25.2	30.4	35.1	37.0	38.6	40.3	40.3	41.6	41.6	43.0	43.0	100

*Fiscal Year 59-60



USGS Sta. 8490
Elevation 111'

FIGURE

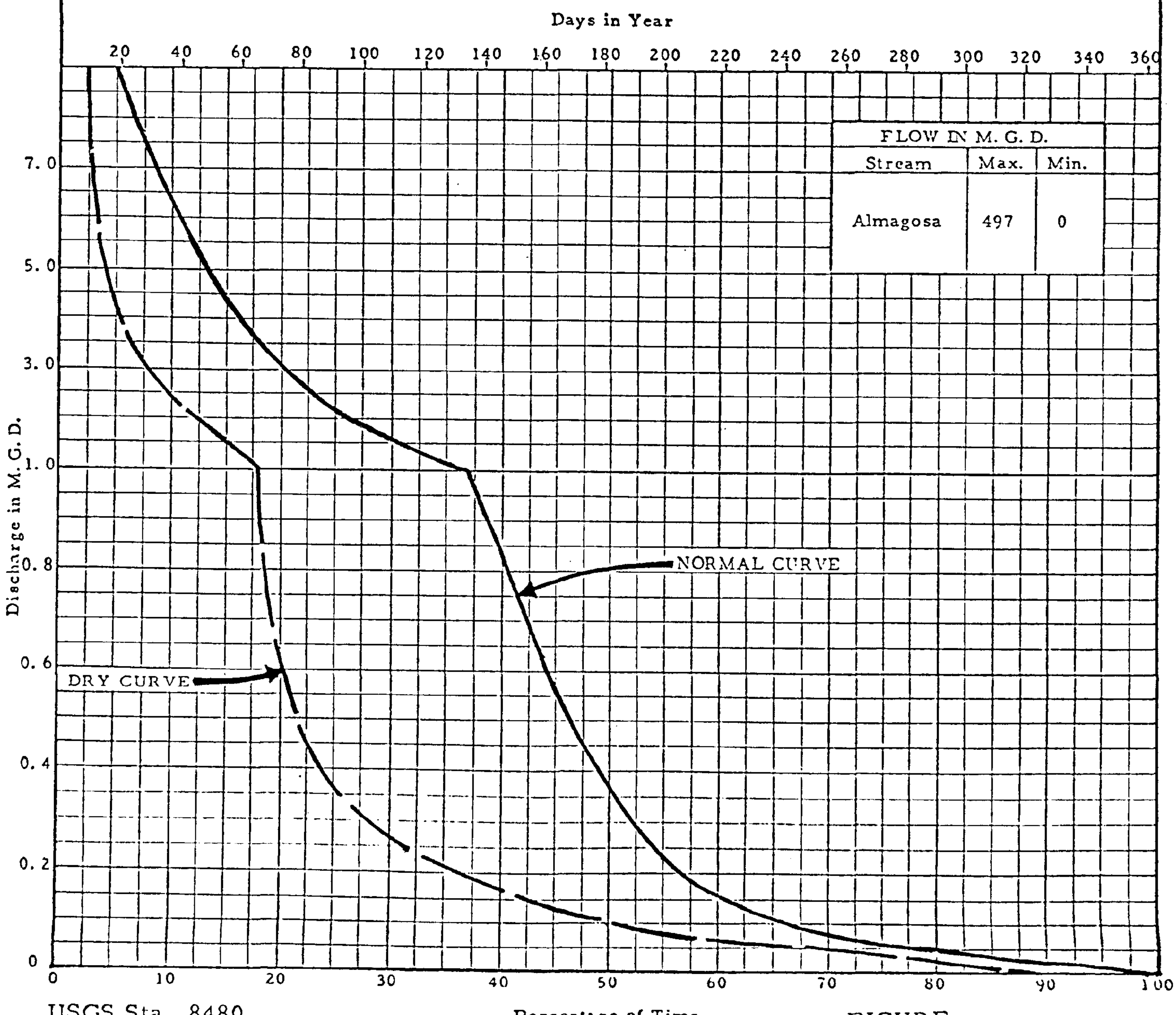
DURATION DISCHARGE CURVE

ALMAGOSA SPRINGS NEAR AGAT

Record - 15 Years
1951 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5754 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	56	149	311	507	760	1186	1549	1787	2114	2534	2838	3251	3801	5754
No. of days in Dry Yr.*	2	7	10	12	16	27	44	56	65	74	85	130	181	365
Percentage of time	0.5	1.9	2.7	3.3	4.4	7.4	12.0	15.3	17.8	20.3	23.3	35.6	49.6	100
No. of days in Av. Yr.	3.5	9.4	19.7	32.2	48.2	75.2	98.3	113.3	134.1	160.7	180.0	206.2	241.1	365
Percentage of time	0.9	2.6	5.4	8.8	13.2	20.6	26.9	31.0	36.7	44.0	49.3	56.5	66.0	100

*Fiscal Year 65-66



USGS Sta. 8480
Elevation 640'±

FIGURE

Measurements. There are five major guaging stations in the Talofofo River basin. The flow duration curves and data from these stations are shown in figures 4-8, 4-9, 4-10, 4-11, and 4-12.

The Talofofo River is guaged at #8500 and recorded from 1951 through 1962. This gauging station is located on the Talofofo just below the intersection of the Maagas and Mahlac Rivers. The average flow at this station is 32.9 mgd and is the largest annual flow recorded on Guam. In the lower reaches, the bulk of this flow results from precipitation runoff, not spring activity, so although the Talofofo River has the highest recorded average flow, it is only third in terms of the 90% case. Ninety percent of the time, the flow is 1.16 mgd, about half that of the Ugum River.[15]

The Talofofo River has four headwater locations. One is on the Tinechong River, 3.41 miles upstream; one on the Mahlac River, 4.22 miles upstream; one on the Bonya River, 6.25 miles upstream, and one on the Maemong River, 8.84 miles upstream from the ocean point of discharge, Talofofo Bay.

Note that both the Maemong and Bonya Rivers flow through underground limestone caverns and disappear as surface flow streams near their confluences. The Maemong disapppears for less than 1,000 feet prior to its confluence with the lower Bonya River (Tolaeyuus) and the Tolaeyuus River disappears as surface flow for less than 2,000 feet above its confluence with the Maagas River. The distance to the headwater locations was calculated as though the rivers were bodies of continuous surface flow.

Guaging station #8450 recorded the flow of the Tolaeyuus River (.05) near Agat (Drainage area = 6.54 sq. mi.) for the period 1951 to 1960. The maximum flow of this river during this period is unknown and the minimum flow is .13 mgd. The average flow at this station is 13.6 mgd. 90% of the time the flow at this station is .52 mgd. The flow duration curves for this station are shown in figure 4-9.

The Imong River near Agat is guaged at station #8470 for a period from 1960 to 1967, during which period a maximum flow of 2180 mgd and a minimum of .24 mgd was recorded. The average flow of the Imong River, which has a drainage area of 1.95 sq. mi., is 6.59 mgd. 90% of the time the flow at this station equals 1.10 mgd.

There are two other major guaging stations in this basin, one for the Fena Dam spillway, #8490, and one for the Almagosa Springs, #8480. The flow duration curves for the Fena station, shown in figure 4-10, has a unique, nearly vertical curve. This curve indicates that the discharge at the spillway is 0 for 56% of the time, but a rather high 10 mgd about 25% of the time.

The Almagosa Springs guaging station lies at an elevation of 640 ft at what is the very origin of the Almagosa River. The maximum flow recorded at this station is 497 mgd, the minimum flow is 0. The elevation, and consequently the potential head of this source, makes it noteworthy. However, the flow is usually rather small at about 3 mgd for 20% of the time, tapering to .1 mgd 6% of the time.

The fact that the military already pumps from the Almagosa Springs, coupled with the required long reaches of expensive penstock, diminishes the impact of this hydro resource.

Power/head characteristics. The majority of the drainage area of the Talofofo River basin lies at elevations greater than 100 feet. The northern tributaries of the Talofofo which include the Talisay, Maemong, Bonya and Talaeyuus, and Mahlac Rivers, all lie on the interior basin, a section of rolling lowlands and karst. Heads of 20 to 25 feet may be created with a minimum of civil works. The elevation of guaging station #8450 is shown to be 90 feet while contour maps show the upper Maagas which is less than 3,500 feet away at an elevation between 20 to 40 feet. This means that there is between 50 to 70 feet of head potential in that section alone. Based on this, it is safe to assume sections with the heads of 30 to 40 feet are available with limited civil works construction such as large impoundment areas or extended penstocks.

This section of the river, however, is the section that flows through underground caverns of limestone, where impoundment leakage could be a problem. Assuming a good impoundment area could be targetted and constructed, power in the order of 57 kW to 75 kW could theoretically be generated beased on the average flow of station #8450 (13.6 mgd) which corresponds to the 23% case. This is based on 30 to 40 foot head, and plant efficiency of 80%. With the same assumptions and using the 50% flow case the instantaneous theoretical potential is between 16.8 kW and 22.5 kW. There are many sections that could support a small farm application of 3 to 10 kW of hydrogenerated power, providing an acceptable potential impoundment area and construction access road are already available.

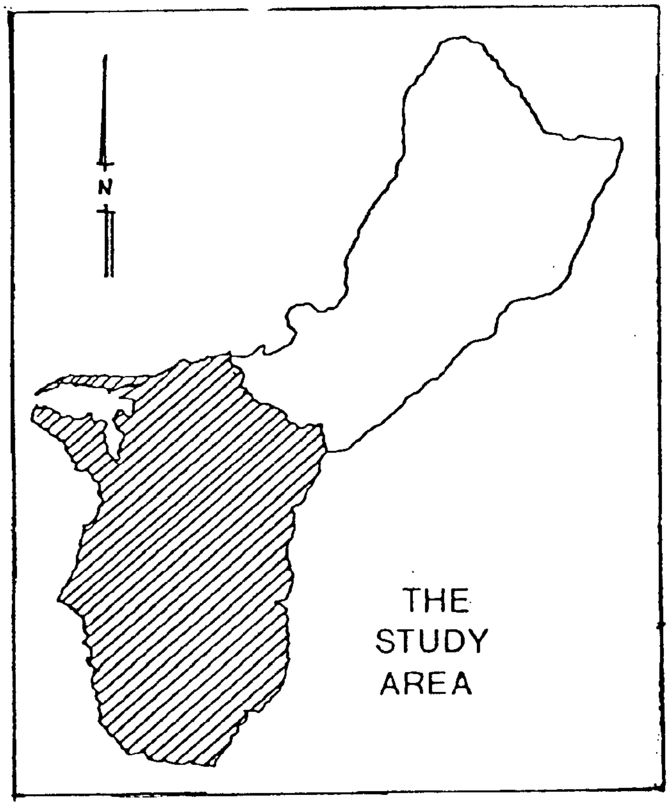
The Fena dam, which presently impounds about 2.3 billion gallons, could be augmented with a 135 kW power plant that could produce 327,069 kWh per year at a plant factor of 32%. This was calculated assuming 75 feet of head, plant efficiency of 80%, and a flow range of 30 to 110% of the design case for the turbine (3 mgd to 15 mgd) based on the amount of water that is presently diverted over the spillway at the dam. This power also could be used right at the dam which has four 3,500 gpm, 300 horsepower pumps installed to deliver the water three miles to the Fena Water Treatment Plant.

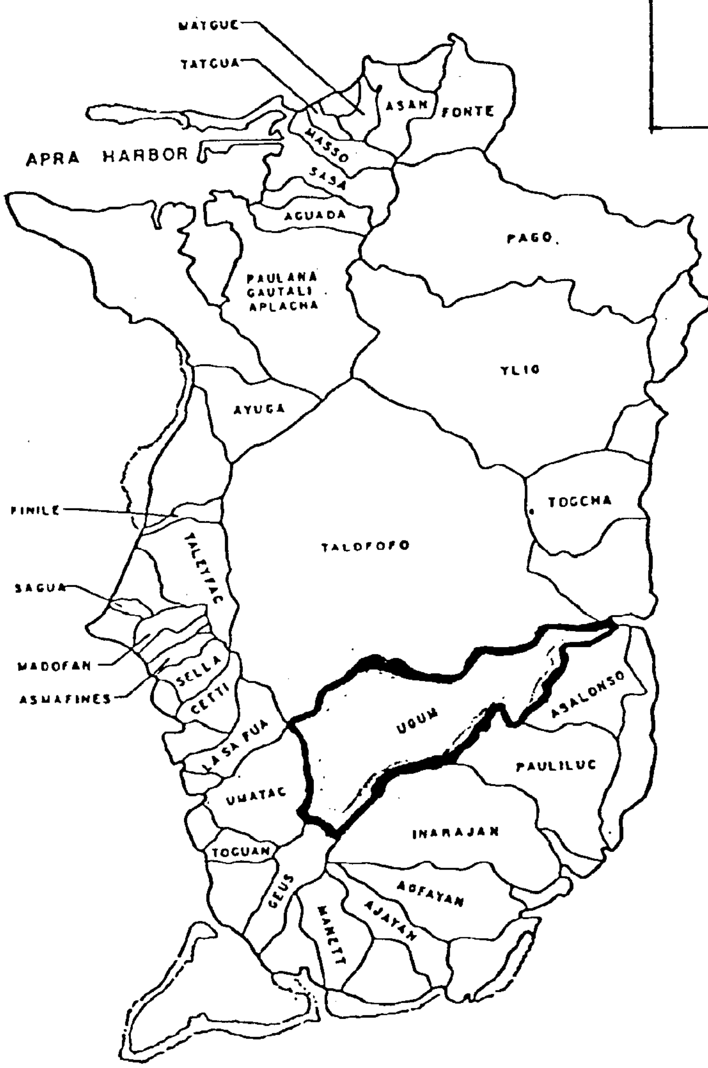
The lower reaches of the Talofofo flows across the alluvial valley floor. This final section of the river has a low gradient which would require the artificial head of a dam. The permeability of the ground would vary, depending on the type of soil deposits found in a particular area. This makes it particularly important to have any potential damsite thoroughly investigated by a professional who could target an area and design a long-lasting, tight dam that would endure.

D. Ugum River

Drainage area = 7.3 sq. mi

Lying immediately south of the Talofofo River basin, the Ugum River drainage area is comprised of the main Ugum River and its major tributary, the Bubualao River. The Ugum River joins the Talafofo about a half mile from its discharge point, Talofofo Bay. Dividing the upper and lower reaches of the river is Talofofo Falls, a scenic tourist attraction.[16]





Geo-physical notes for the Uguam River basin

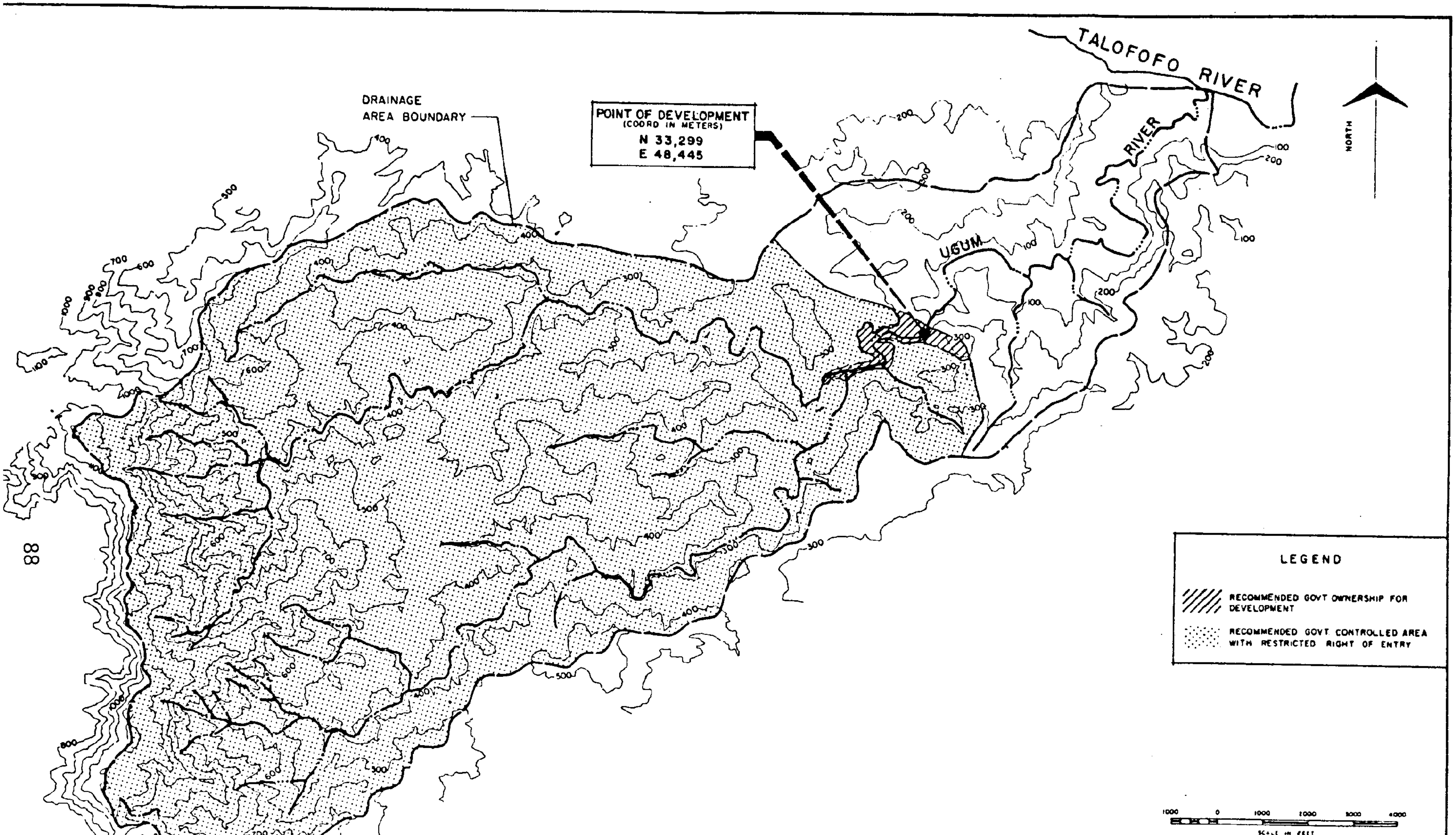
General - mostly underlain with deeply weathered, consolidated, non-calcareous sediments derived from volcanic rock.

Upper reaches - soils composed of Atate-Agat clays.

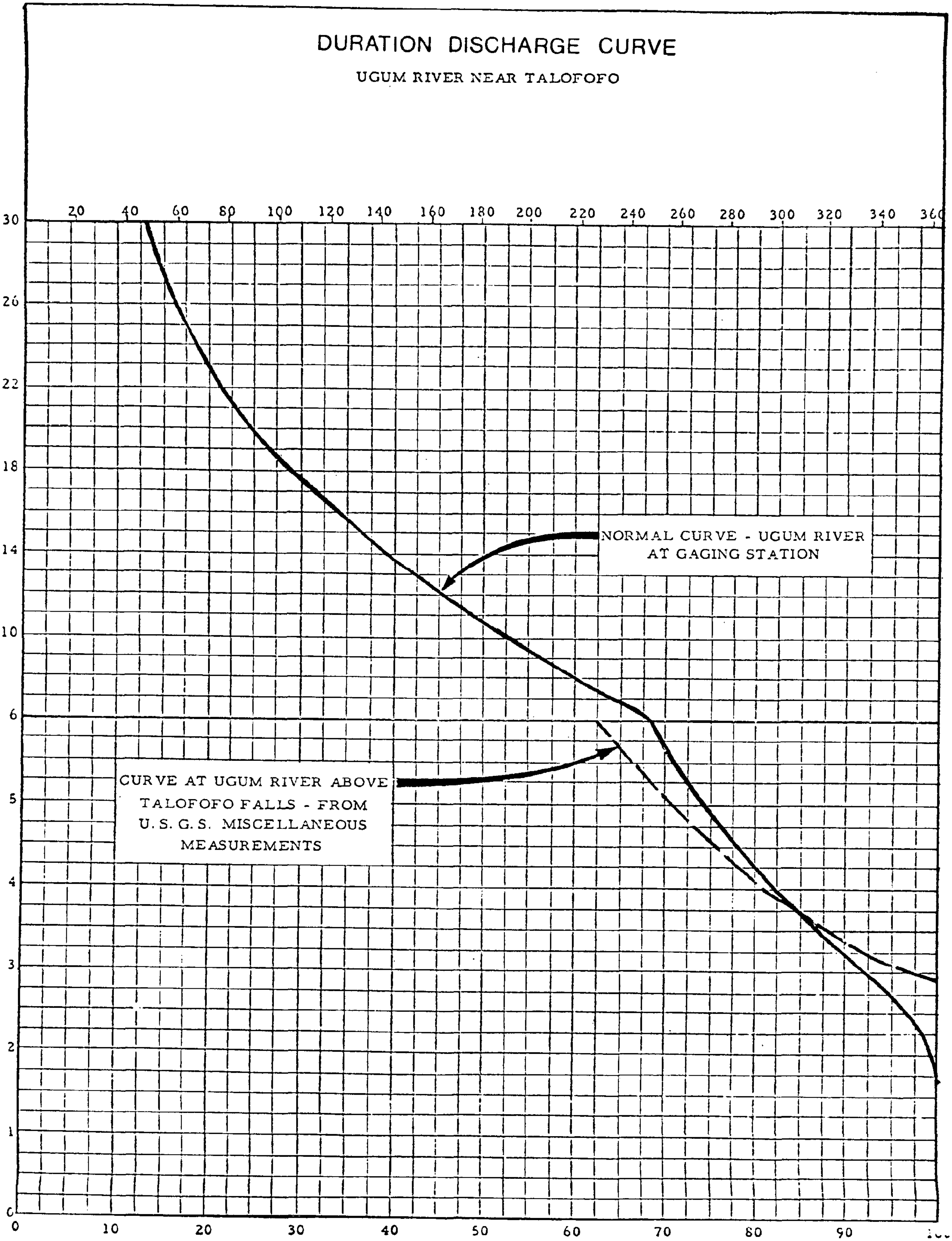
Lower reaches - valley flats underlain by alluvium and soils composed of moderatedly well-drained Pago clays.

Talofofo Falls - dense basaltic rock outcropping dividing the upper and lower river reaches.

Point of discharge - Talofofo River.[17]



UGUM RIVER DRAINAGE AREA



USGS Sta. 8550
Misc. Measurements

FIGURE

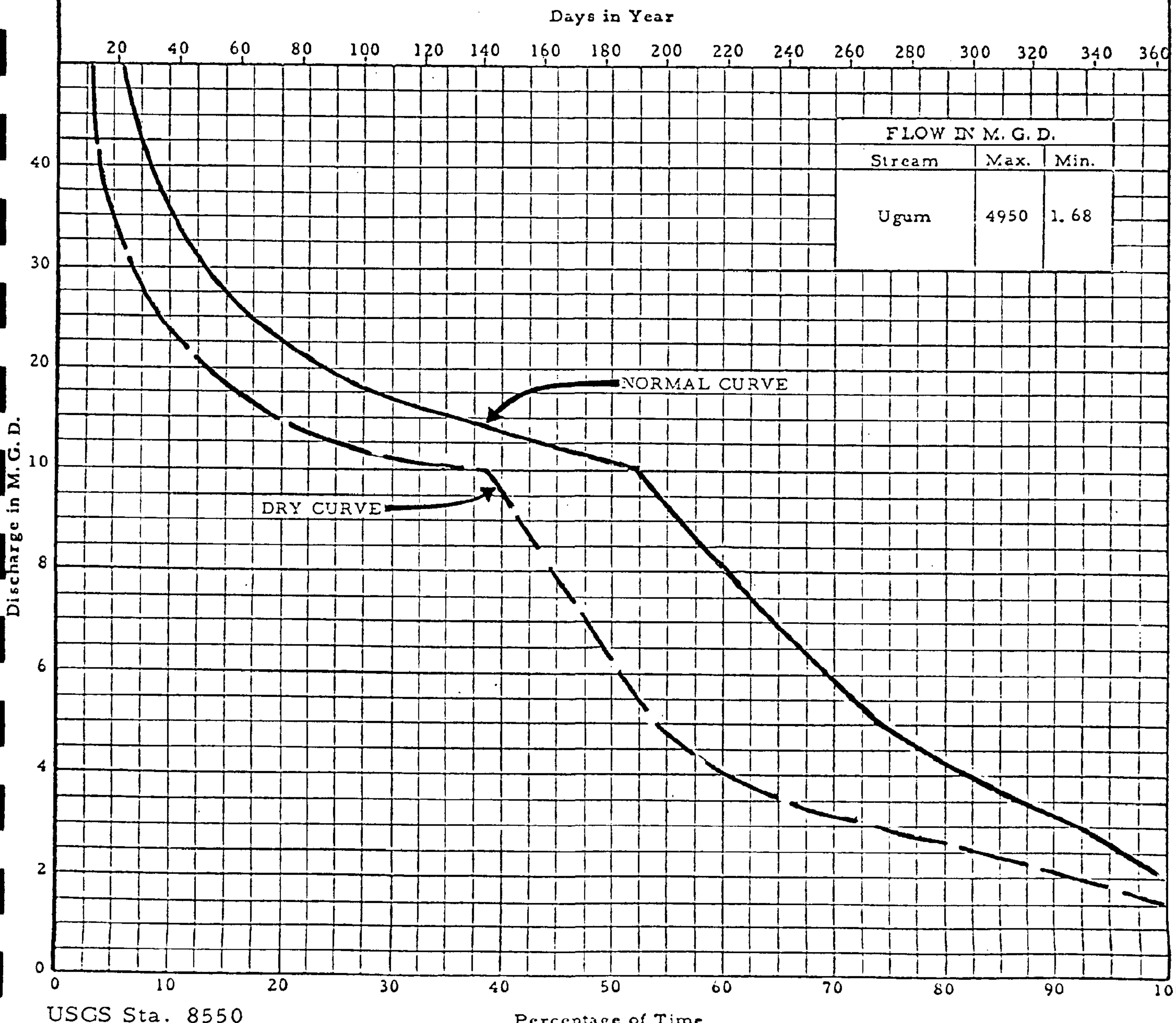
DURATION DISCHARGE CURVE

UGUM RIVER NEAR TALOFOFO

Record - 15 Years
1952 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5491 Days	75	50	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2
(Partial Years Included)	177	319	962	1983	2895	3563	4086	5072	5461	5491	5491	5491	5491	5491
No. of days in Dry Yr.*	7	12	32	69	139	174	199	269	335	365	365	365	365	365
Percentage of time	1.9	3.3	8.8	18.9	38.1	47.7	54.5	73.7	91.8	100	100	100	100	100
No. of days in Av. Yr.	12	21	64	132	192	237	272	333	363	365	365	365	365	365
Percentage of time	3.2	5.8	17.5	36.1	52.7	64.9	74.4	92.4	99.5	100	100	100	100	100

*Fiscal Year 65-66



USGS Sta. 8550
Elevation 3.23'

FIGURE

Measurements. The flow duration curves and data for the Ugum are shown in figures 4-14 and 4-15. These measurement records show that the flows vary from a maximum of 4,950 mgd to a minimum of 1.68 mgd, for a period of record of 5,491 days.

The Ugum is guaged near its confluence with the Talofofo River. The average flow at this station, #8550, is 19.0 mgd. 90% of the time the flow equaled or exceeded 3.30 mgd, the highest 90% case on Guam. The Ugum has two headwater locations, one on the main Ugum River at a point 6.05 miles upstream from its confluence with the Talofofo, and one on the Bubualao River, 2.78 miles upstream from its confluence with the Ugum River.

Other measurements were taken during the low flow years from 1961 to 1966 at a guaging station located about 3,000 feet upstream from Talofofo Falls. The measurements from this station revealed that at a guaged flow of less than 3.76 mgd, the flow upstream was greater than the flow at the downstream guaging station. This happens due to the discharge of the numerous small seeps and springs in the upper reaches of the Ugum River basin which contribute significantly to the stream flow during low flow periods. The tight clay formations underlaying the upper reaches prevent seepage. Consequently, the river flow increases until it hits those downstream sections underlain by the porous or less saturated soils which soak up the streamflow before it reaches the downstream guaging station.[18]

The effect is dramatic. On April 4, 1968, the Ugum flow was measured immediately above the Talofofo Falls showing a flow of 9 mgd while the guaging station downstream measured only 5.2 mgd. It is thought that the dense basaltic rock barrier of the Falls forces the seepage flows to the surface in order for it to pass over the Falls. Once over and past the falls, the water slowly seeps back into the more porous soil of the alluvium, at a rate dependent on the ground water level within the soil and the gradient of the stream.[19]

In the Geological Survey Professional Paper 403-H, entitled Hydrology of Guam by Ward, Hoffard and Davis, 1965,[20] this Ugum River phenomenon is discussed with reference to the Inarajan, Pago and Ylig River basins. Sections of this report are reproduced below for reference:

> ...the Ugum River has the lowest rate of recession of base flow among the major streams on Guam. The stream basin is mainly in hilly upland underlain by conglomerate, breccia, and sandstone and shale beds. Diffuse ground-water discharge from the fragmental rock maintains the low flow of the stream. The lowest daily discharge during the period of record was 3.4 cfs (cubic feet per second).
>
> The low flows in the Inarajan and Umatac Rivers are smaller and somewhat less sustained than the low flow of the Ugum. The geology of the basin of the Inarajan is similar to that of the Ugum basin and the low flow in the stream is maintained by diffuse ground-water discharge and by small springs at the heads of gulleys in the mountainous part of the basin. Small springs in lavas and limestone lenses within the lavas supply the low flow of the Umatac River.
>
> The rock in the basins of the Ylig and Pago Rivers above the guaging points is mostly fine-grained tuff grading to fine sandstone. This terra apparently absorbs less rainfall and

> has less ground-water storage than the rock in the basin of the Ugum River, which has a comparable size. Consequently, the low flow in the Ylig and Pago Rivers may drop to or near zero during droughts.
>
> The variability of low flow among the streams of Guam is shown also in the low-flow frequency curves for the Ugum River and the Pago River. In the Ugum River, the lowest 1-day mean discharge at a recurrence interval of 10 years is 3.4 cfs. This same flow in the Pago River is the lowest 60-day mean discharge likely to occur every 1.1 years. The lowest 60-day mean discharge having a 1.1 year recurrence interval in the Ugum River is about 12 cfs. This spread in low-flow magnitudes and frequencies is large in view of the fact that the average discharge in the Ugum River is only about 20 percent greater than that of the Pago River.

Power/head combinations. The bulk of the Ugum River flows at an elevation higher than 100 feet. Over 80% of the basin is above the 200 foot contour. In terms of potential head, this drainage area is among the best, with numerous sections having 25 to 50 head available with low civil works requirements. The premium sections are those in the vicinity of the confluence of the Ugum and Bubulao River, but a small (2-10 kW) hydro plant location could theoretically be targetted anywhere on the main Ugum River from the headwater location on down to the valley flats provided a suitable impoundment area and access road were available. The head/flow combinations required to support a 10 kW plant are found beginning at the headwater locations of the Ugum and Bubulao extending downstream to just below Talofofo Falls.

The site of the proposed Ugum River dam is by the far the best site for a hydro installation on Guam. The plan for the proposed dam is to impound 12 mgd of water, 9 mgd of which would be retained for irrigation and agricultural uses while maintaining the streamflow with a 3 mgd discharge. With just the addition of a power plant at the proposed dam, over 400,000 kWh of power could be generated in a year using the daily 3 mgd discharge. This translates into 33,333 kWh per month, which would power a sizable single facility or about 50 homes. This calculation is based on a head of 110 feet and a plant efficiency of 85%.

If the daily discharge were doubled then 800,000 kWh could be generated in a year or 100 homes could be provided with electrical power.

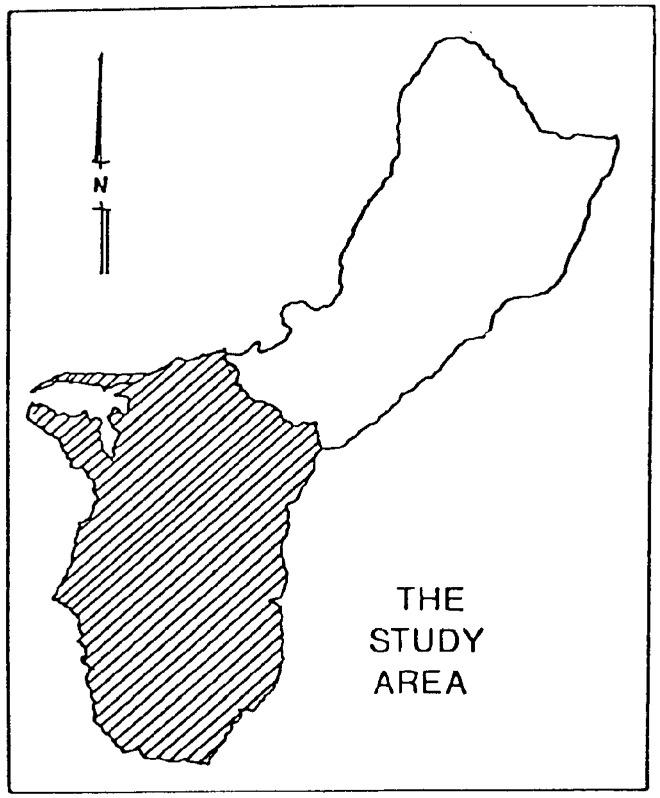
Furthermore, if the power plant were placed at the proposed dam, then the discharge could be reused downstream as the head permits. Theoretically, as the river flows from the dam power plant (elevation 190 ft.) to the Talofofo River (elevation 20 ft.), seventeen 100 foot dams could be built to use the 3 mgd discharge, producing over 4 kW each, for a total of over 71 kW of additional power.

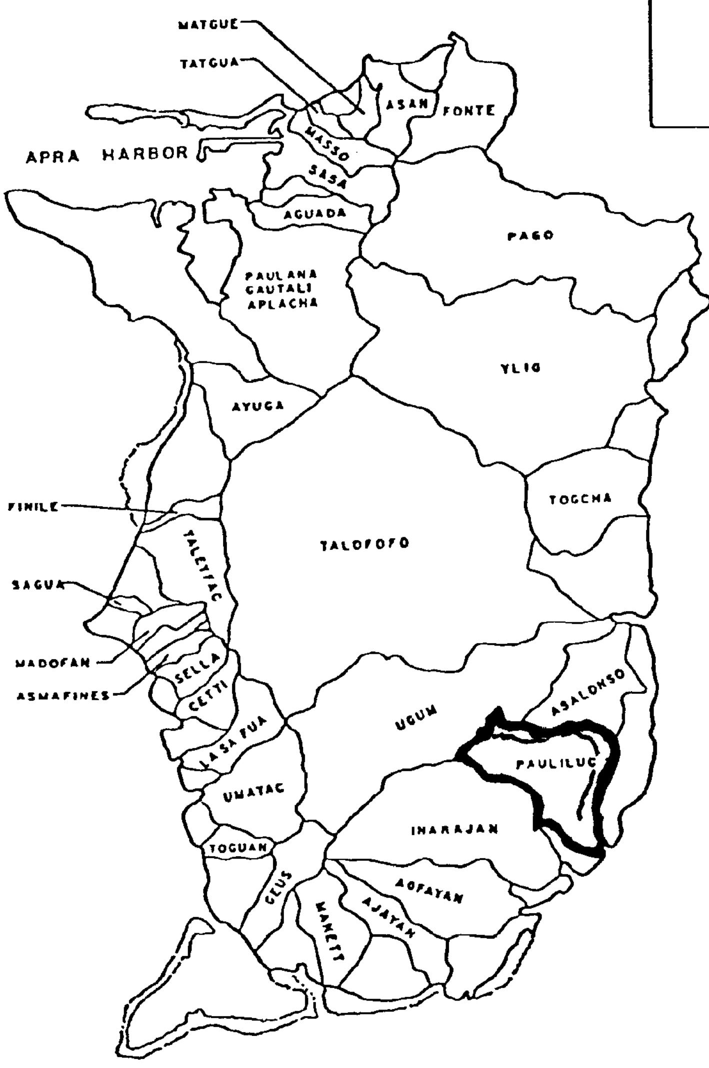
As mentioned earlier, professional soil expertise would be particulary necessary in targetting impoundment areas in the Ugum lower alluvial reaches.

E. Pauliluc River

Drainage area = 3.5 sq mi

Located in the southeastern section of the study area and sorrounded by the Ugum, Asalonso, and Inarajan River basins, the Pauliluc drainage area is comprised of the main Pauliluc River and its two major tributaries, the Aslinget and Tinaga Rivers. The confluence of these two rivers is located about two thousand feet upstream of the Pauliluc Bay where they join to form the Pauliluc River.[21]





Geo-physical notes for the Pauliluc River basin.

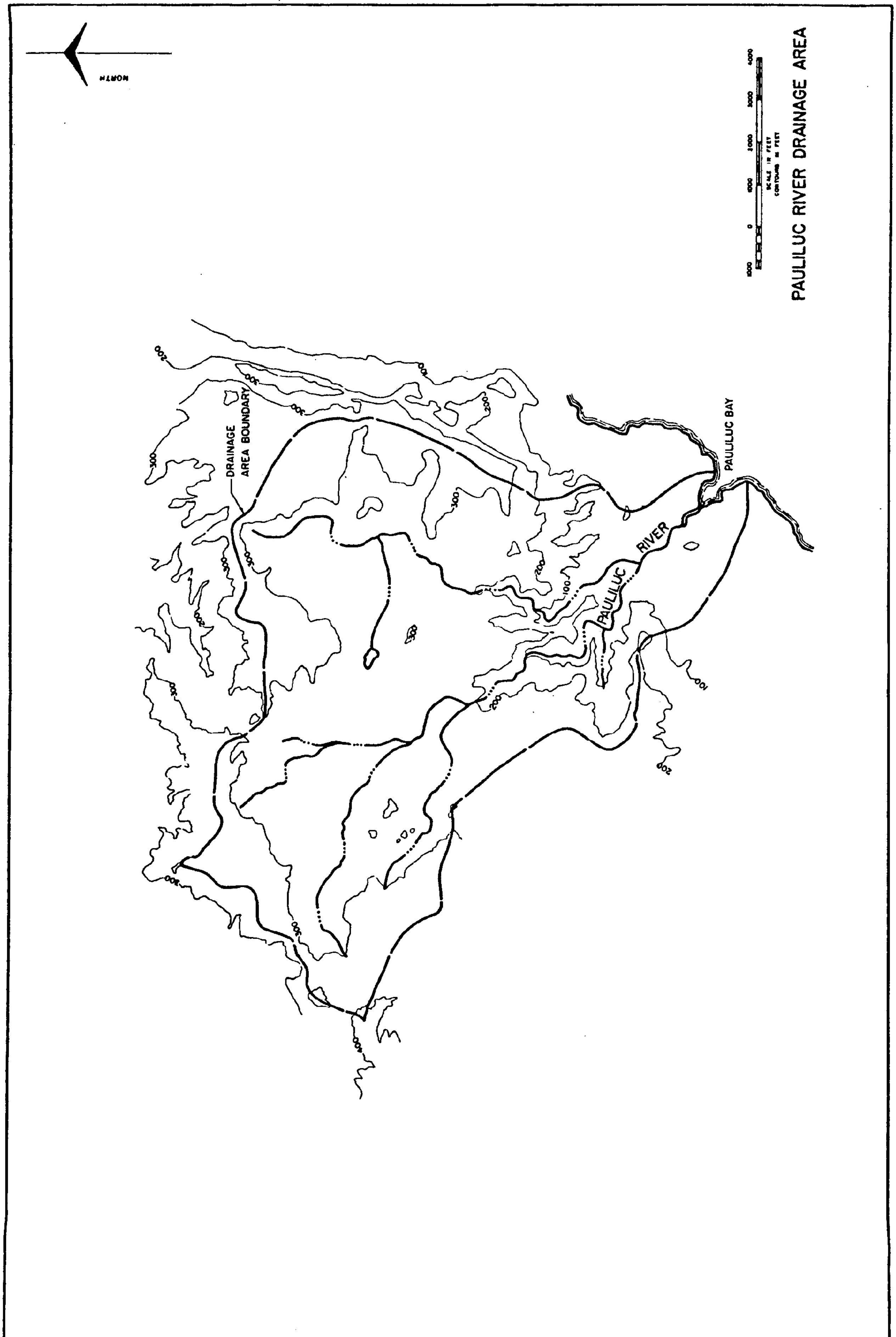
General - rolling terrain, mostly underlain by deposits of breccia, conglomerates, sandstone and shale derived from volcanic rock.

Upper reaches - region of gently rolling areas. Stream and tributaries have low gradient.

Lower reaches - approximately one mile upstream from its mouth, the stream gradient steepens through narrow walled valley producing several small waterfalls.

Sediment - the water has a high sediment content. The suspended material in the water, which discharges from the marshy area in the upper reaches during low flow periods, gives it a red color.

Point of discharge - Pauliluc Bay, southeastern coast of Guam.[22]

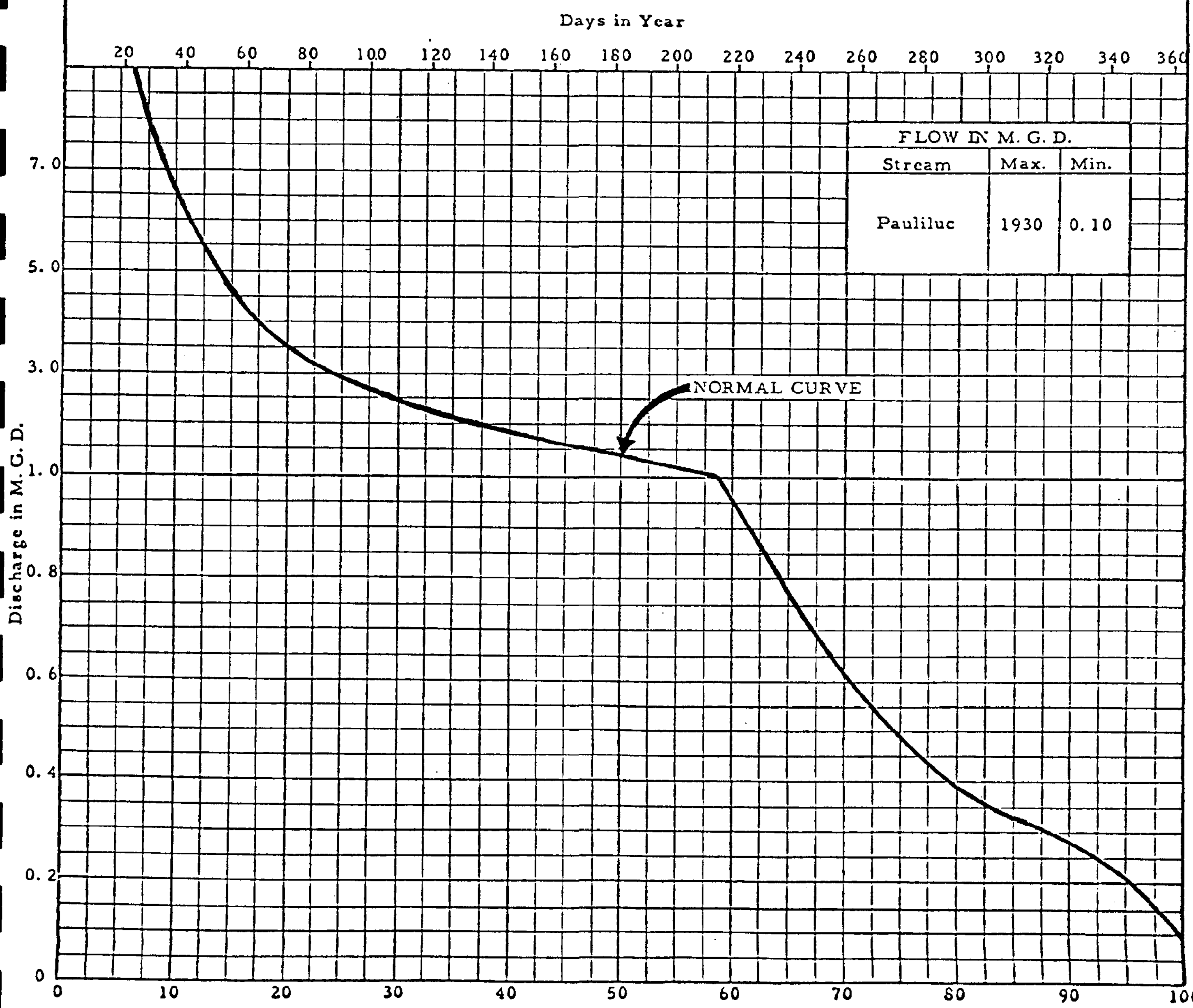

PAULILUC RIVER DRAINAGE AREA
NORTH
DRAINAGE AREA BOUNDARY
PAULILUC RIVER
PAULILUC BAY
100
200
300
400

DURATION DISCHARGE CURVE

PAULILUC RIVER NEAR INARAJAN

Record - 14 Years
1952 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5383 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	132	234	345	497	741	1309	1973	2439	3160	3780	4262	5192	5383	5383
No. of days in Dry Yr.														
Percentage of time														
No. of days in Av. Yr.	8.9	15.8	23.4	33.7	50.2	88.7	133.8	165.4	214.3	256.3	289.0	352.0	365	365
Percentage of time	2.4	4.3	6.4	9.2	13.8	24.3	36.6	45.3	58.7	70.2	79.2	96.4	100	100



USGS Sta. 8400
Elevation 20'±

FIGURE

Measurements. The flow duration curves and data are shown in figure 4-17 for a period of record from 1952 to 1967. This guaging station #8400 is located above the confluence of the Tianaga and Aslinget Rivers and measures only the flow of the Tinaga River which has a drainage area of 1.89 sq. mi. (54% of the total Pauliluc River drainage area). Since the Aslinget River is not guaged, the flow can only be estimated based on the proportional size of its drainage area relative to the Tinaga drainage area. Based on this method of estimation, Aslinget River flow could be assumed to be roughly 85% of the flow for the Tinaga River.

The average flow of the Tinaga River is 3.68 mgd, and the 90% flow case is .26 mgd. The highest streamflow recorded for the Tinaga is 1930 mgd, while the minimum flow was recorded at .1 mgd. The Tinaga headwater location is .97 miles upstream from the Pauliluc discharge point, Pauliluc Bay.

The average flow of the Aslinget is estimated to be 3.13 mgd. The headwater location for the Aslinget is .83 mles upstream from its confluence with the Tinaga.

Power/head characteristics. Approximately 80% of the Pauliluc drainage area is at an elevation above 200 feet. The majority of this area is rolling hills at elevations between 200 and 300 feet.

There is a section on both the Tinaga and Aslinget Rivers that falls from the 200 foot contour to the 100 foot contour in less than 2,000 feet. Provided that an impoundment area could be located near this section, a 50 foot head could reasonably be projected. The most attractive head/flow combinations are located from just above the 200 foot contour down to immediately below the guaging station.

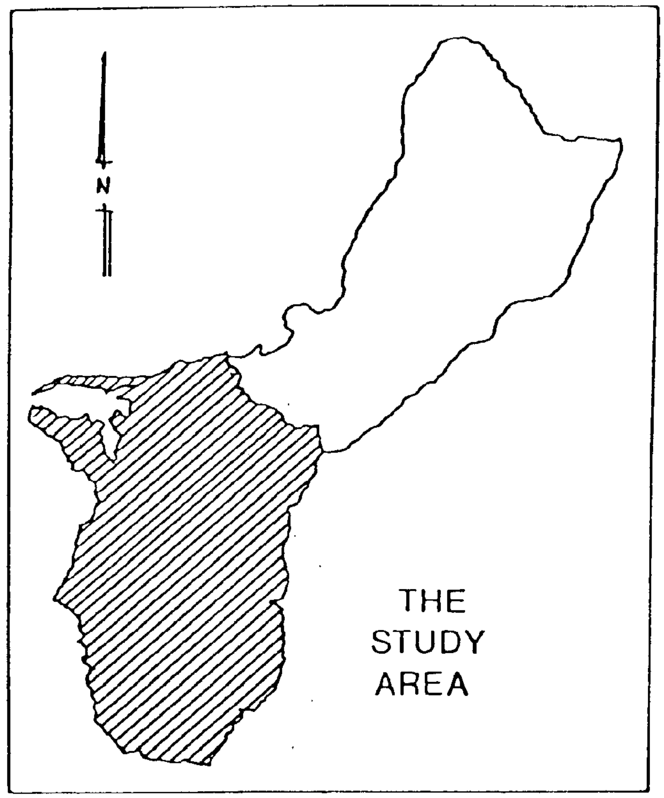
Unfortunately, there are specific limiting factors to hydro development on the Pauliluc basin. First, the flows are small when compared to its neighbor river basins, the Ugum and the Inarajan Rivers. Second, the upper reaches of the Pauliluc are inhabited and the rolling hills are used for pasture land. Consequently, control of bacterial pollution and chemical contamination would be extremely difficult, eliminating any attactive water sales to the Public Utilities Agency of Guam. Finally, the high sediment content of the river could be a potential maintenance problem to the turbine blades in the form of pitting.[23]

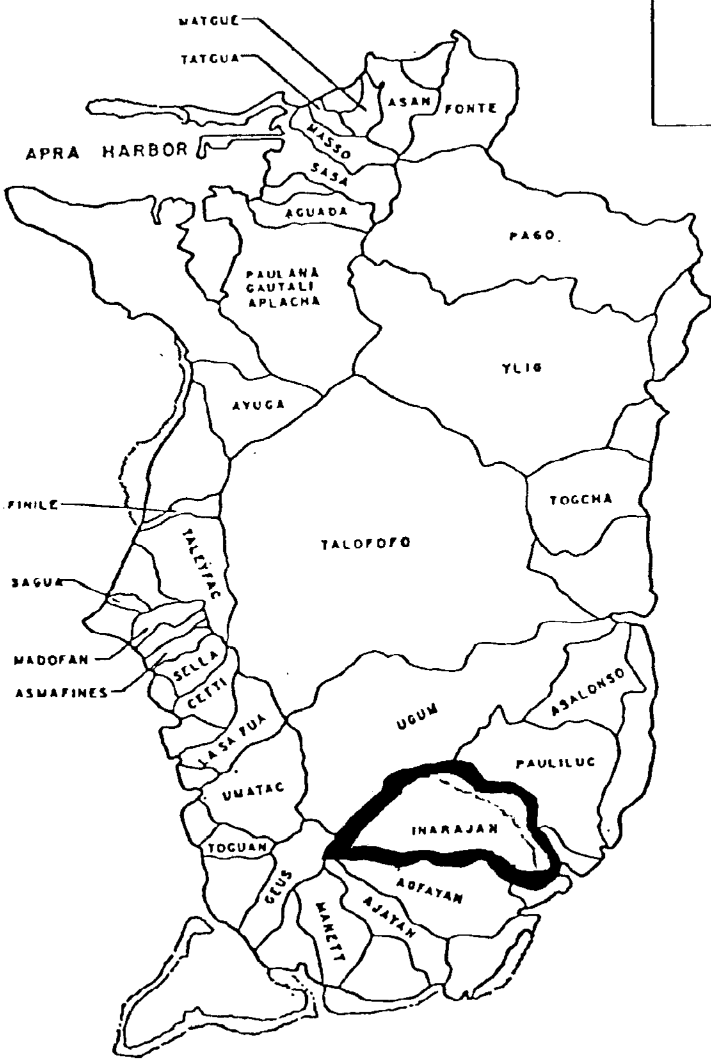
Assuming the pitting problem could be addressed, a plant on the Tinaga designed to use 3 mgd (30-110% of the design case) at 50' head, could generate 87,000 kWh a year from a 20 kW plant.

F. Inarajan River

Drainage area = 5.0 sq mi

The Inarajan River basin is located in the southern section of the study area, just south and adjacent to the Ugum and Pauliluc drainage areas. the river basin is comprised of two main tributaries, the Pasamano and Laolao Rivers and the main Inarajan River which is formed at the confluence of the tributaries at a point .8 miles upstream from the ocean discharge point, Inarajan Bay.[24]





Geophysical notes for the Inarajan River Basin

General - approximate basin dimensions, 3.5 miles long, 2 miles wide.

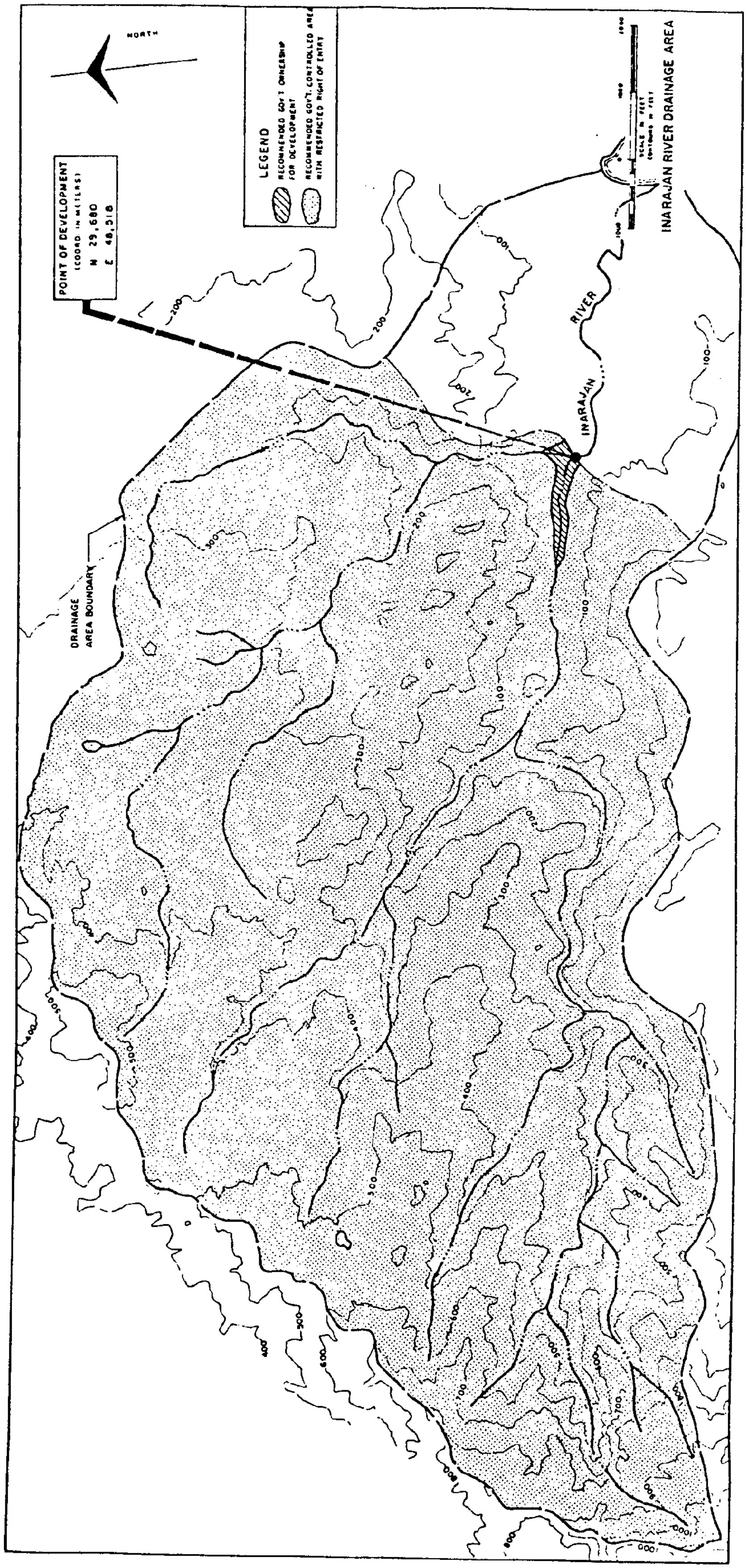
Two main branches - flow in small gorges over much of their stream length.

Upper reaches - numerous small seeps and springs at the heads of the gorges in mountainous portions of the basin which contribute to the base flow of the drainage.

East fork of the North Branch - supplies the village of Inarajan with average of 50,000 gpd for domestic water supply.

Lower reaches - coastal lowlands and alluvial valley floors.

Point of drainage - Inarajan Bay, southern coast of Guam.[25]


NORTH
POINT OF DEVELOPMENT
(COORD IN METERS)
N 29,680
E 48,518
LEGEND
RECOMMENDED GOV'T OWNERSHIP FOR DEVELOPMENT
RECOMMENDED GOV'T CONTROLLED AREA WITH RESTRICTED RIGHT OF ENTRY
DRAINAGE AREA BOUNDARY
INARAJAN RIVER
INARAJAN RIVER DRAINAGE AREA

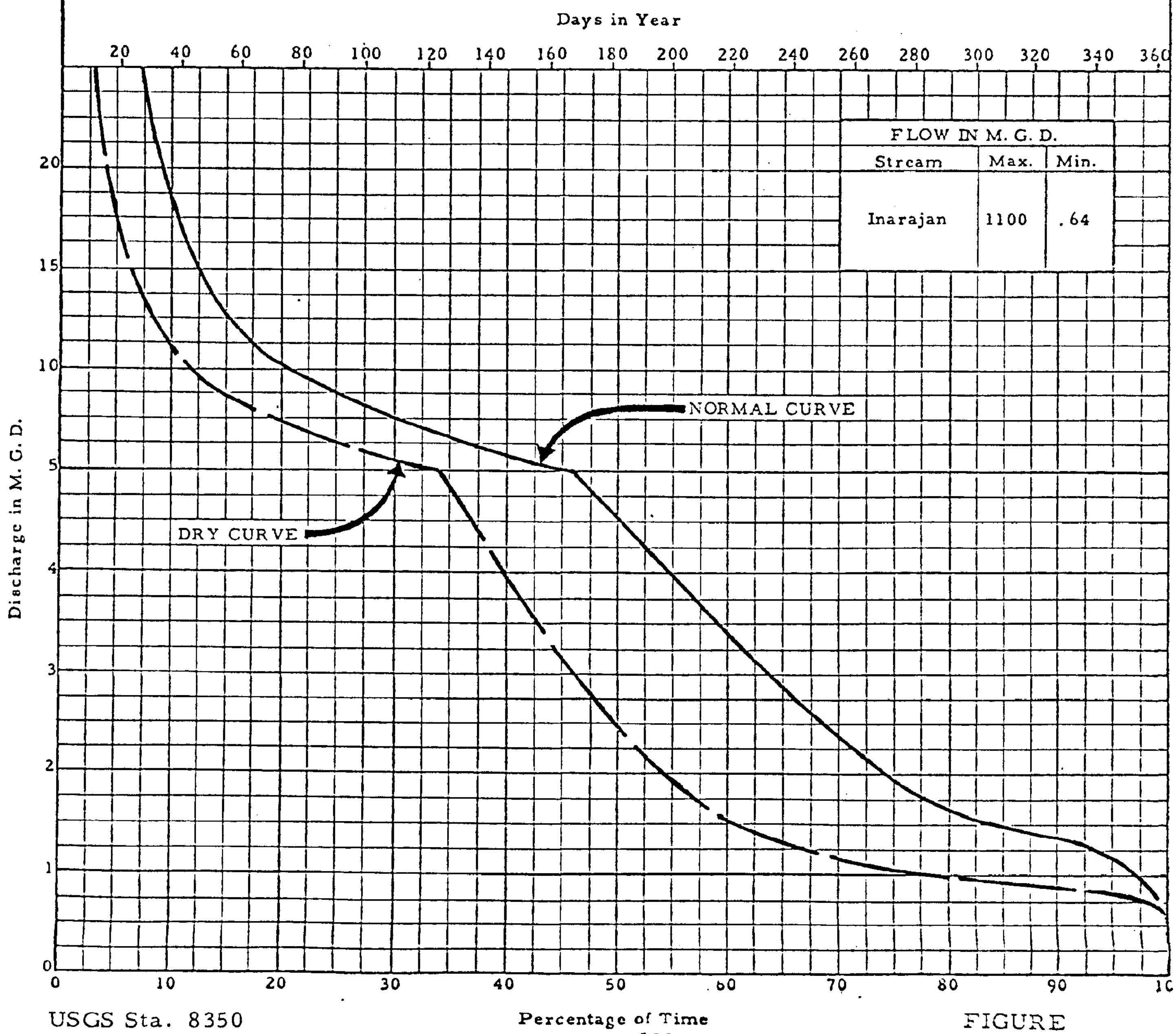
DURATION DISCHARGE CURVE

INARAJAN RIVER NEAR INARAJAN

Record - 14 Years
1952 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5404 Days	50	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1
(Partial Years Included)	197	398	676	1136	1791	2462	3414	4042	4517	5245	5404	5404	5404	5404
No. of days in Dry Yr.*	7	11	23	38	80	124	169	197	222	289	365	365	365	365
Percentage of time	1.9	3.0	6.3	10.4	21.9	34.0	46.3	54.0	60.8	79.2	100	100	100	100
No. of days in Av. Yr.	13.3	26.9	45.7	76.7	121.0	166.3	230.6	273.0	305.1	354.3	365.0	365.0	365.0	365.0
Percentage of time	3.6	7.4	12.5	21.0	33.1	45.6	63.1	74.8	83.6	97.1	100	100	100	100

*Fiscal Year 65-66



USGS Sta. 8350
Elevation 25'±

FIGURE

Measurements. The flow duration curves and data are shown in figure 4-19. These measurement records show that the flows vary from a maximum of 1100 mgd to a minimum of .64 mgd for a period of record of 14 years. The Inarajan is measured at guaging station #8350, located approximately a halfmile above its mouth. The average flow is 11.2 mgd. The headwater locations for the Inarajan River fall on two major tributaries. The first is located 2.7 miles upstream from Inarajan Bay on the Pasamano River. The other is located .4 miles upstream from the confluence of the Laolao and the Inarajan.[26]

Power/head characteristics. The majority of the Inarajan drainage area lies at elevations above 100 feet. The configuration of the tributaries, however, is such that the stretches of high flow have a low gradient. There are three major tributaries which join the network about a mile apart from each other. The first joins the network at the headwater location on the Pasamano River, very near to the 200 foot contour and is the farthest upstream tributary. The other two tributaries join the Inarajan network inside the 60 foot and 40 foot contours. As a result, where there is higher head potential (25 to 50 feet) there is the smallest flow, and where there is high flow, there is little potential to develop heads over 2 to 30 feet. If a penstock were dropped down far enough at the Pasamano headwater to develop 160 feet of head, then the instantaneous theoretical power potential would be 73 kW (assuming q = 5 cfs; e = 80%). This would require over a mile of penstock at a cost of about $40.00 per running foot, or a cost of approximately $211,000.00 for penstock alone. If the Pasamano and Yledigao, the next tributary, where joined by diverting one of them then approximately 123 kW could be generated (based on the same efficiency, head, and approximating the flow to be 8.5 cfs based on the combined drainage areas). This hydro strategy, which is discussed in Chapter II.C.4, is only applicable in special cases and is the worst strategy in terms of economic and environmental considerations. Should the cost of oil continue to escalate, however, many such alternatives will emerge as viable due to the inflationary oil costs.

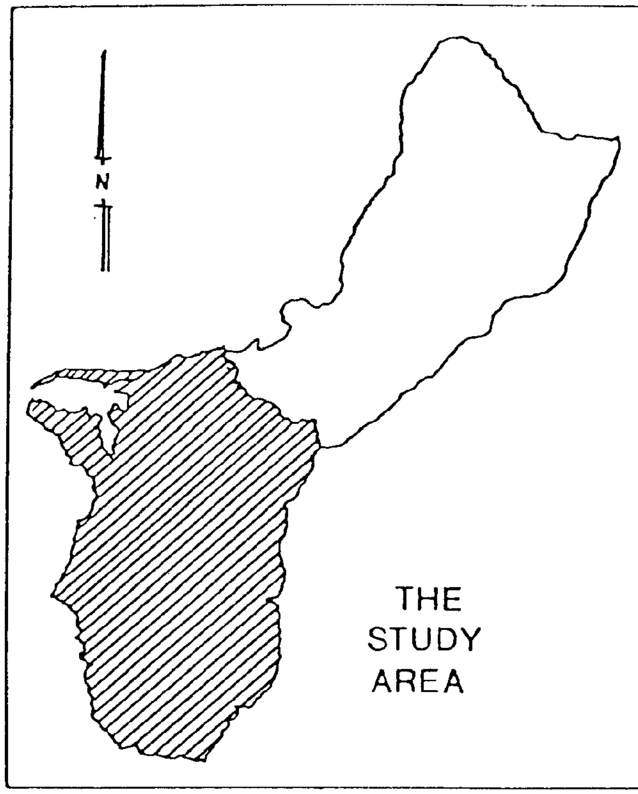
The U. S. Army Corps of Engineers have targetted a potential impoundment area on the Inarajan River at its confluence with the LaoLao River. Based on Army data, the maximum theoretical instantaneous power generation at the proposed am would be 76 kW. This is calculated based on a head of 102 feet, a flow of 5.17 mgd and an efficiency of 85%. Assuming the power plant would use only the water discharged to maintain streamflow (1.3 mgd), the generation potential drops to 19 kW.

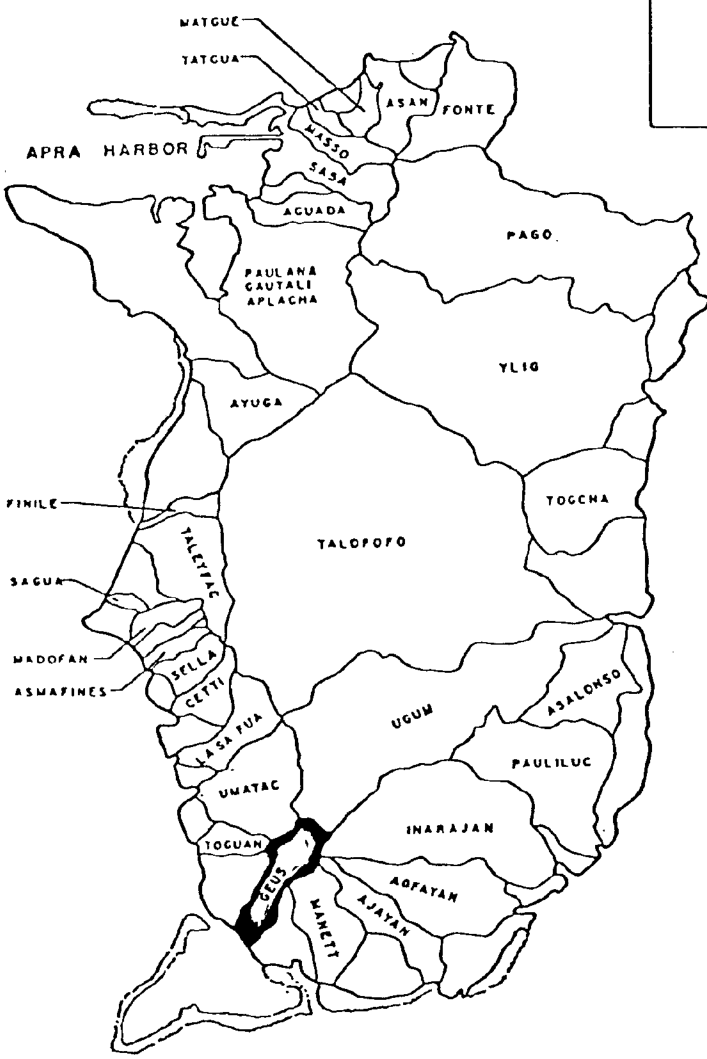
As is the case with most of Guam's streams, there are many locations in the drainage system which could support a small farm or home generation plant in sizes of 2 to 10 kW, providing a suitable impoundment area could be located with access. The best head/flow combinations for this would be on sections on both the Pasamano and Yledigao Rivers from the headwater locations down to the proposed dam on the Inarajan main body.

G. Geus River

Drainage area = 1.5 sq mi

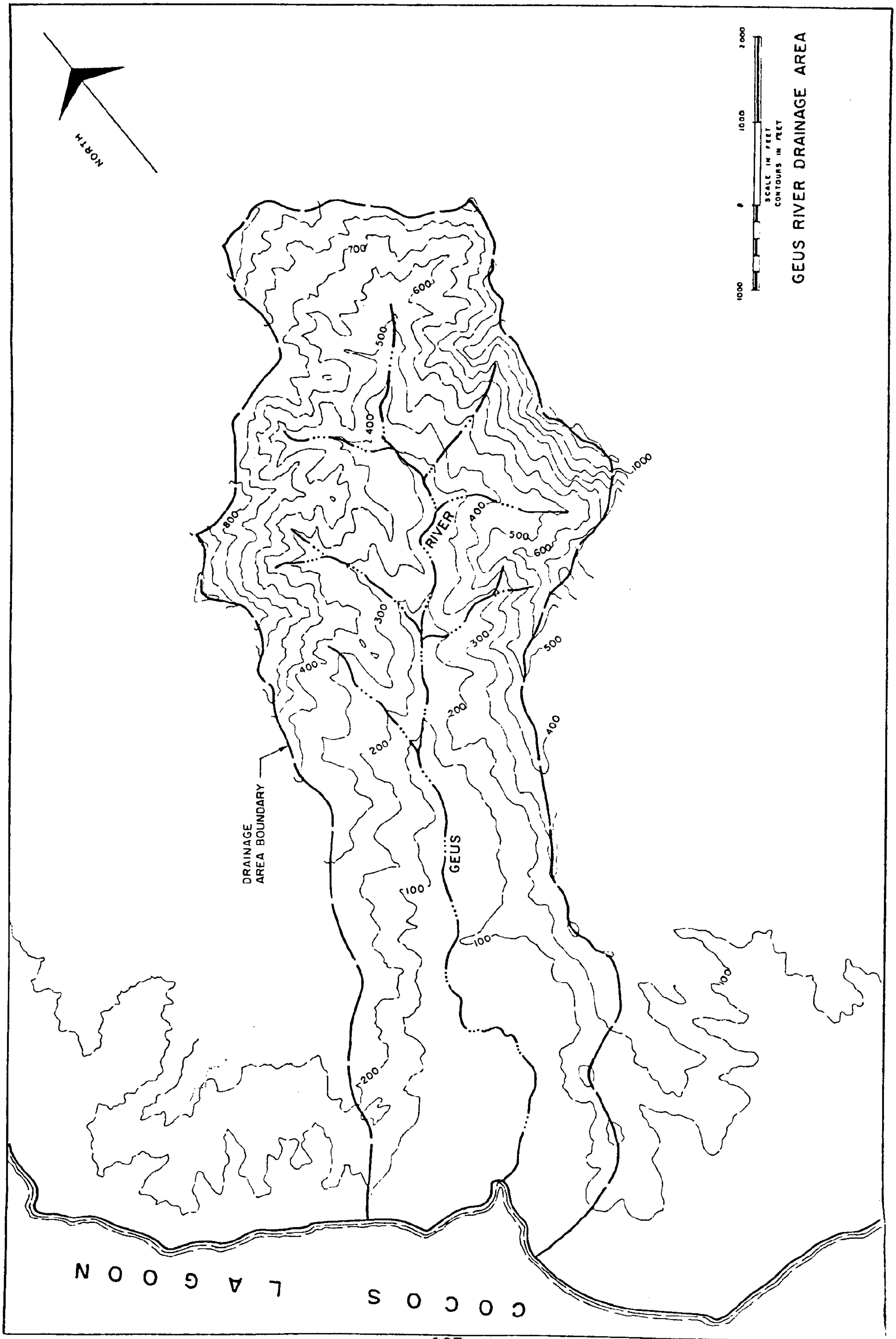
The Geus River basin is located on the southwestern tip of the study area and is comprised of a single main body fed by several springs which maintain the flow in the dry season. The village of Merizo is supplied its present water supply from this river, just below Siligin Springs, the largest group in the supply system.[27]





Geo-phyisical notes for the Gues River basin.

General - mountainous land underlain by lava flows, breccia, and conglomerate.
Upper reaches - steep gradient flowing through narrow, steep walled valley.
Lower reaches - gentle gradient flowing through a narrow flat valley underlain by alluvium.
Point of discharge - Cocos Lagoon, southern tip of Guam.[28]


GEUS RIVER DRAINAGE AREA
SCALE IN FEET
CONTOURS IN FEET
1000
0
1000
2000
NORTH
DRAINAGE AREA BOUNDARY
GEUS
RIVER
COCOS LAGOON

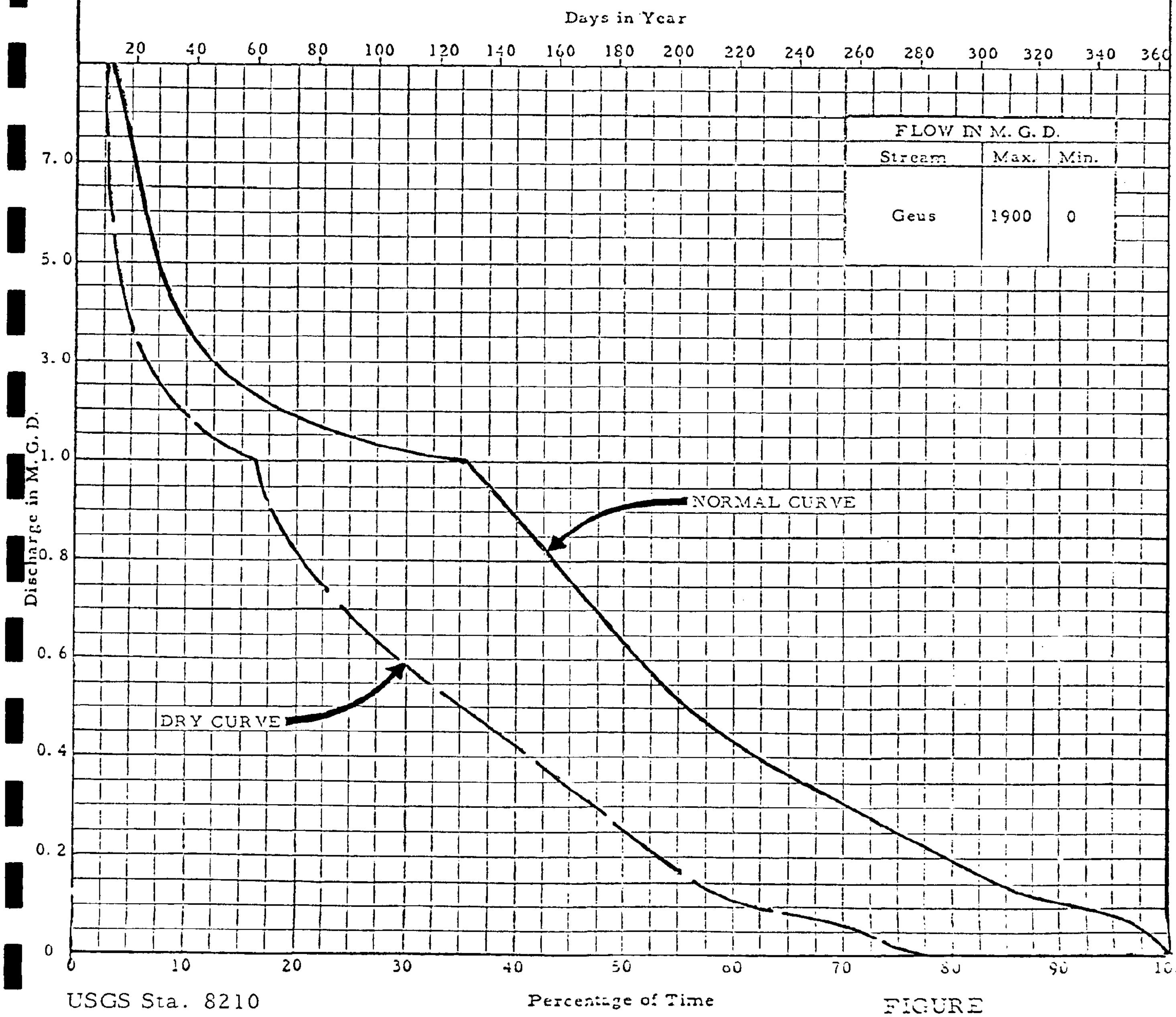
DURATION DISCHARGE CURVE

GEUS RIVER NEAR MERIZO

Record - 14 Years
1952 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
5188 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	56	116	202	281	396	650	953	1242	1844	2669	3223	4120	4785	5188
No. of days in Dry Yr.*	3	5	10	10	15	22	32	41	59	106	152	192	228	365
Percentage of time	0.8	1.4	2.7	2.7	4.1	6.0	8.8	11.2	16.2	29.0	41.6	52.6	62.5	100
No. of days in Av. Yr.	3.9	8.2	14.2	19.8	27.8	45.7	67.0	87.4	129.7	187.8	226.7	289.8	336.6	365.0
Percentage of time	1.1	2.2	3.9	5.4	7.6	12.5	18.4	23.9	35.5	51.4	62.1	79.4	92.2	100

*Fiscal Year 65-66



USGS Sta. 8210
Elevation 85'±

FIGURE

Measurements. The flow duration curves and data for the Geus River area are shown in figure 4-21. These measurement records show that the flows vary from 1900 mgd to 0 for a period of record from 1952 to 1967. This data was recorded at guaging station #8210, located about one mile upstream from its mouth. In a normal year the river basin produces less than .25 mgd for 25% of the year, compared with a drought year during which it is dry for 23% of the year. The average flow at station #8210 is 1.95 mgd. The headwater location is set by the Army Corps of Engineers at a point .32 miles downstream of the guaging station.[29]

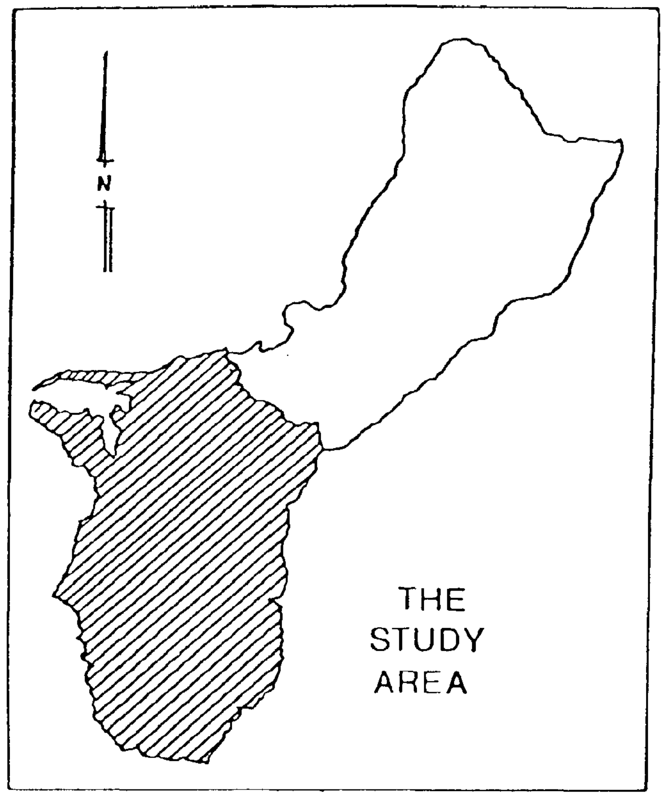
Siligan Springs produces .030 to .020 mgd, and supplies Merizo with part of its domestic water supply.

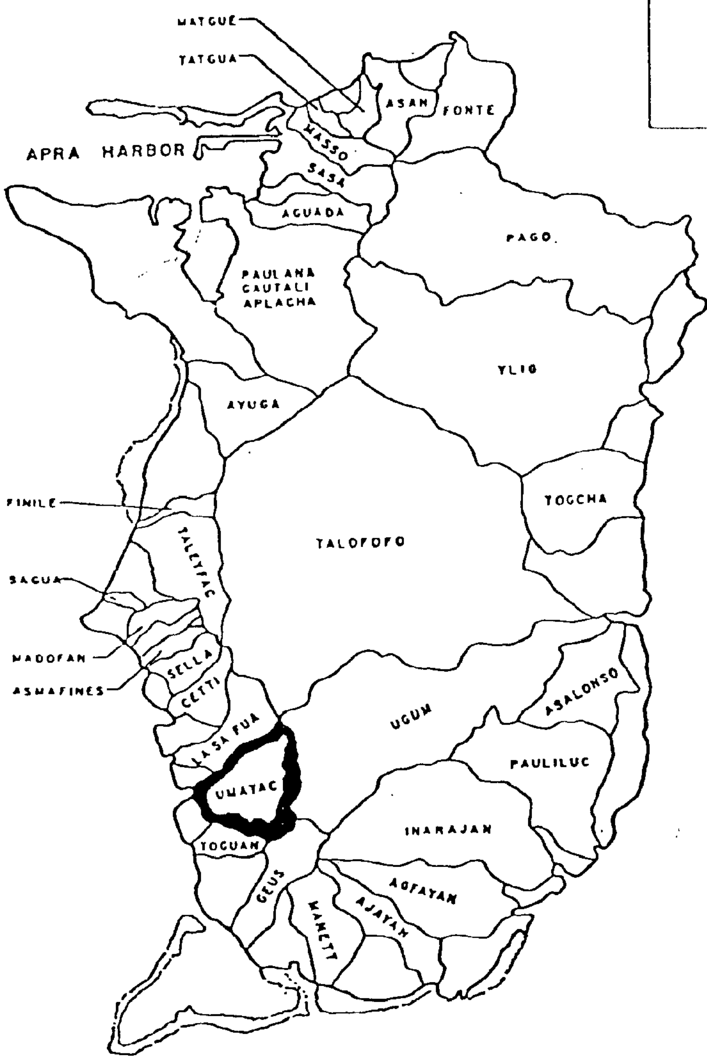
Power/head characteristics. Due to the low flow ratio for this system combined with the fact that it has already been developed as a water supply source for Merizo, it is a low priority candidate for hydro generation. There are sections of the river beginning at the 200 foot contour down to the headwater location that could yield heads from 30 to 50 feet, but the power generation potential is limited to small applications of less than 12 kW. This is an upper limit estimate considering the fact that as Merizo's water demand increases the downstream hydro potential decreases.

H. Umatac River

Drainage area = 2.1 sq mi

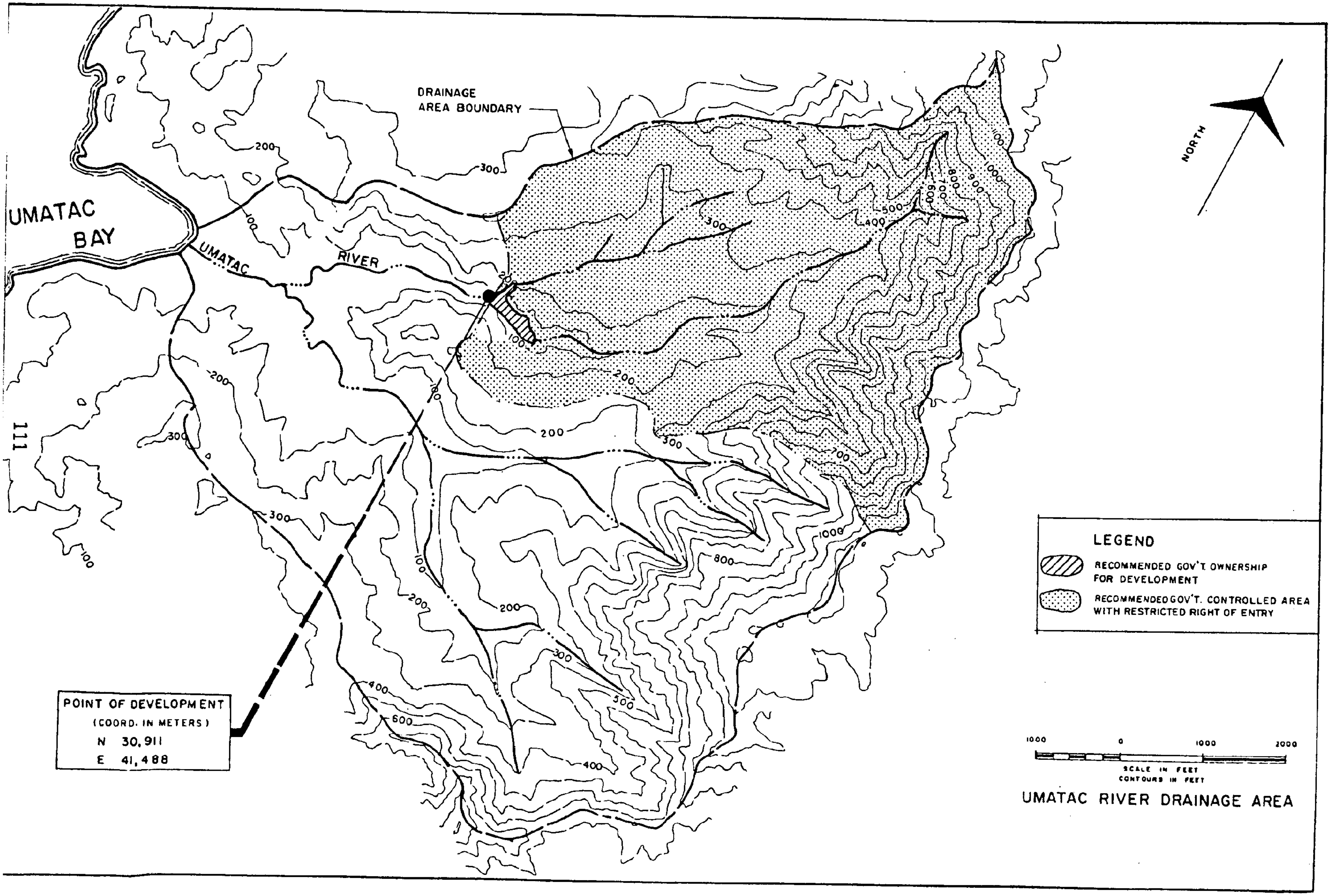
Located in the southwestern section of the study area, the Umatac River drainage area is composed of the main Umatac River and its two major tributaries, the Laelae and Madog River. These rivers join to form the Umatac River .24 miles upstream from its mouth at Umatac Bay.[30]





Geo-physical notes for Umatac River basin.

General - mountainous lands underlain mostly by lava flows and assorted limestone beds.
Upper reaches - steep gradient with stream fed by small seeps and springs issuing from lava flows.
Lower reaches - gentle gradient in a valley flat underlain by alluvium.
Point of discharge - Umatac Bay, southwestern coast of Guam.[31]


UMATAC BAY
UMATAC RIVER
DRAINAGE AREA BOUNDARY
NORTH
LEGEND
RECOMMENDED GOV'T. OWNERSHIP FOR DEVELOPMENT
RECOMMENDED GOV'T. CONTROLLED AREA WITH RESTRICTED RIGHT OF ENTRY
POINT OF DEVELOPMENT
(COORD. IN METERS)
N 30,911
E 41,488
1000 0 1000 2000
SCALE IN FEET
CONTOURS IN FEET
UMATAC RIVER DRAINAGE AREA

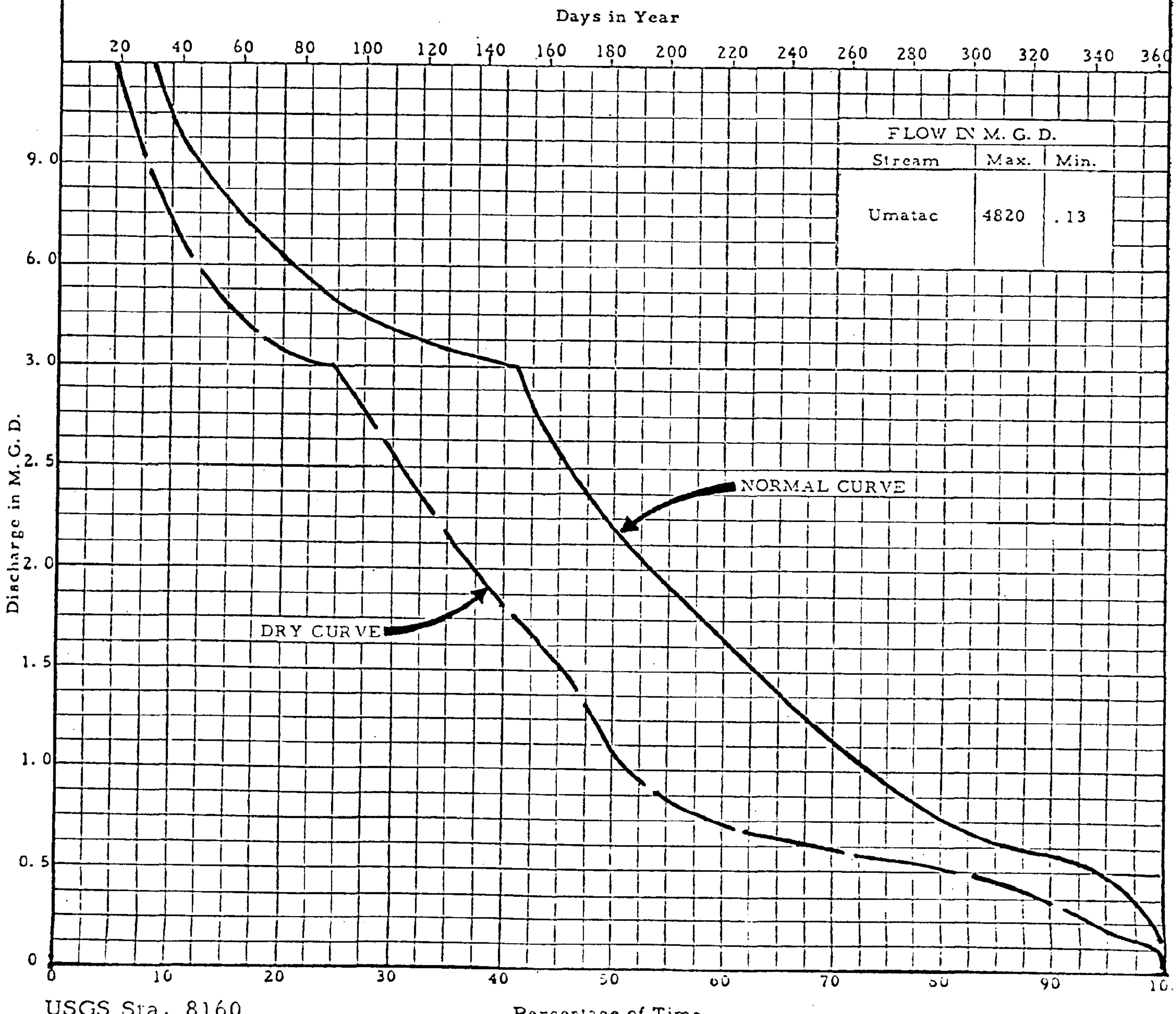
DURATION DISCHARGE CURVE

UMATAC RIVER NEAR UMATAC

Record - 14 Years
1952 - 1967

Period of Record 5406 Days	Discharge Equal to or Exceeding - in M. G. D.													
	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	217	379	591	925	1339	2225	2904	3410	3966	4800	5289	5385	5406	5406
No. of days in Dry Yr.*	8	12	25	38	52	90	136	168	188	254	321	348	365	365
Percentage of time	2.2	3.3	6.8	10.4	14.2	24.7	37.3	46.0	51.5	69.6	87.9	95.3	100	100
No. of days in Av. Yr.	14.7	25.6	39.9	62.3	90.4	150.2	196.1	230.2	267.8	324.1	357.1	363.6	365.0	365.0
Percentage of time	4.0	7.0	10.9	17.0	24.8	41.2	53.7	63.1	73.4	88.8	97.9	99.6	100	100

*Fiscal Year 65-66



USGS Sta. 8160
Elevation 12'±

FIGURE

Measurements. The flow duration curves and data for the Umatac River are shown in Figure 4-23. The measurement records show that the flows vary from 4830 mgd to .13 mgd for a period of record of fourteen years from 1952 to 1967. The average flow measured at guaging station #8160, is 5.62 mgd. The Umatac has one headwater location on the Madog River, a major tributary. This is located .38 miles upstream from Umatac Bay.[32]

The bulk of the low flows come from the right branch based on miscellaneous measurements of this stream. Even in three low flow periods the base flow in the Umatac and its tributaries is maintained by the numerous small springs and seeps in the upper reaches of the river basin. The largest, Piga Spring, supplies the village of Umatac with part of its domestic water supply.[33]

Power/head characteristics. Over a third of the river bodies in this basin lie at elevations of less than 100 feet. The remaining sections climb to an elevation of 300+ feet where the streams originate.

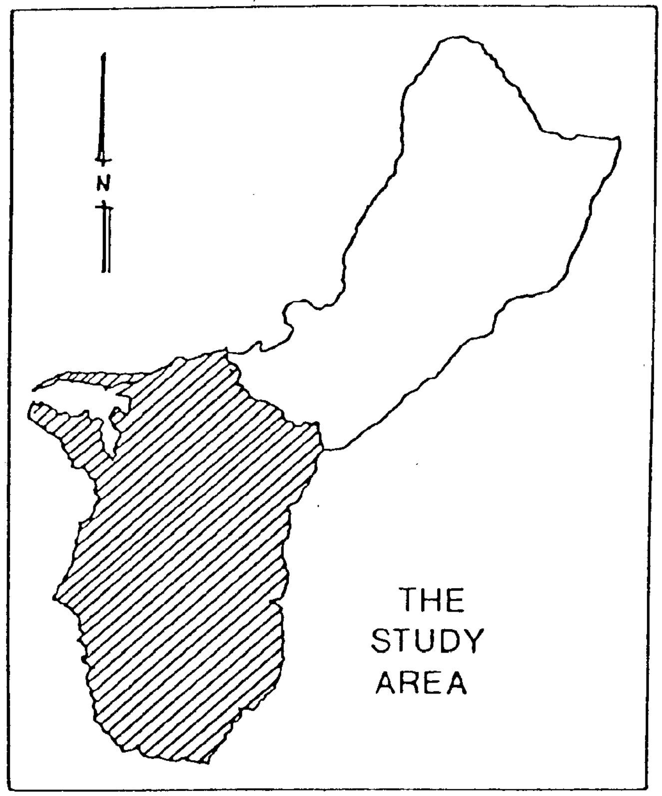
The elevation at the guaging station is about 12 feet. This section of the river continues downstream at a gradual fall. As in the case of the Pago River, any head over 5 to 10 feet would have to be developed artificially at the dam.

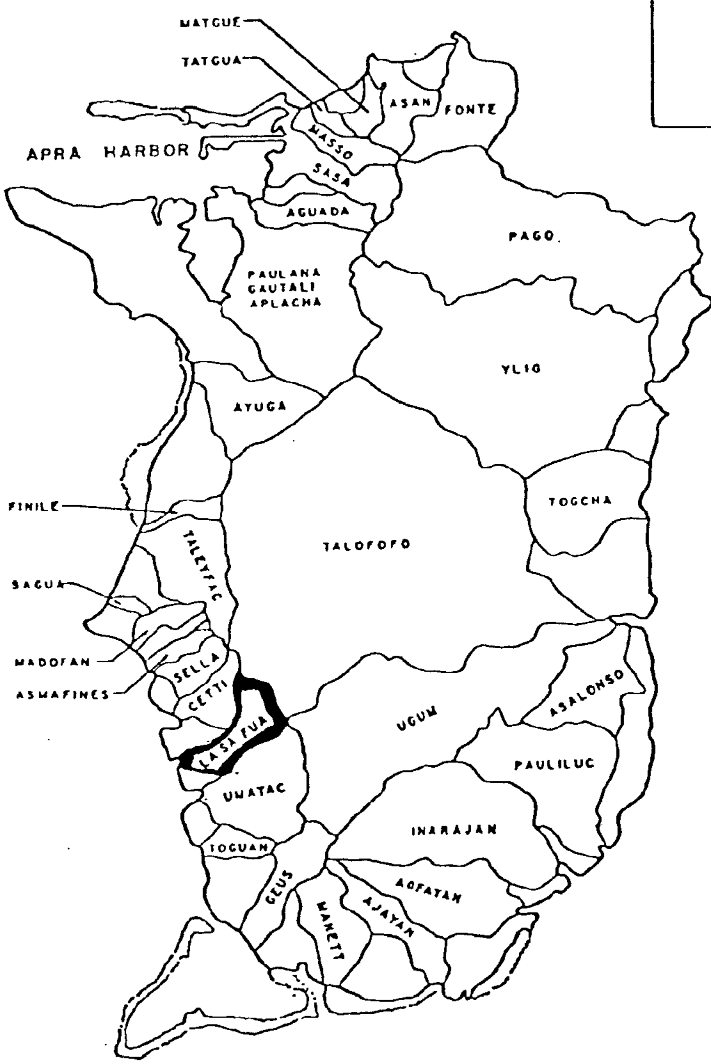
Above the guaging station where the river tributaries branch apart, the average flow is divided and there is inadequate flow to support any sizable hydro installation. The head/flow combinations are adequate to support a 5 kW plant about 10% of the time, but the cost feasibility is bleak except in special farm cases where off-season labor might be used to deter the substantial cost of civil works requirements using farm resources. These factors combined with the fact that the water is already being diverted to supply Umatac makes this a low priority basin in terms of hydroelectric development.

I. La Sa Fua River.

Drainage area = 1.2 sq mi

Located in the western section of the study area, the La Sa Fua drainage area is composed of the main river body and several high elevation tributaries. Although this drainage area is small it is noteworthy due to its consistently steep gradient which allows substantial natural heads.[34]

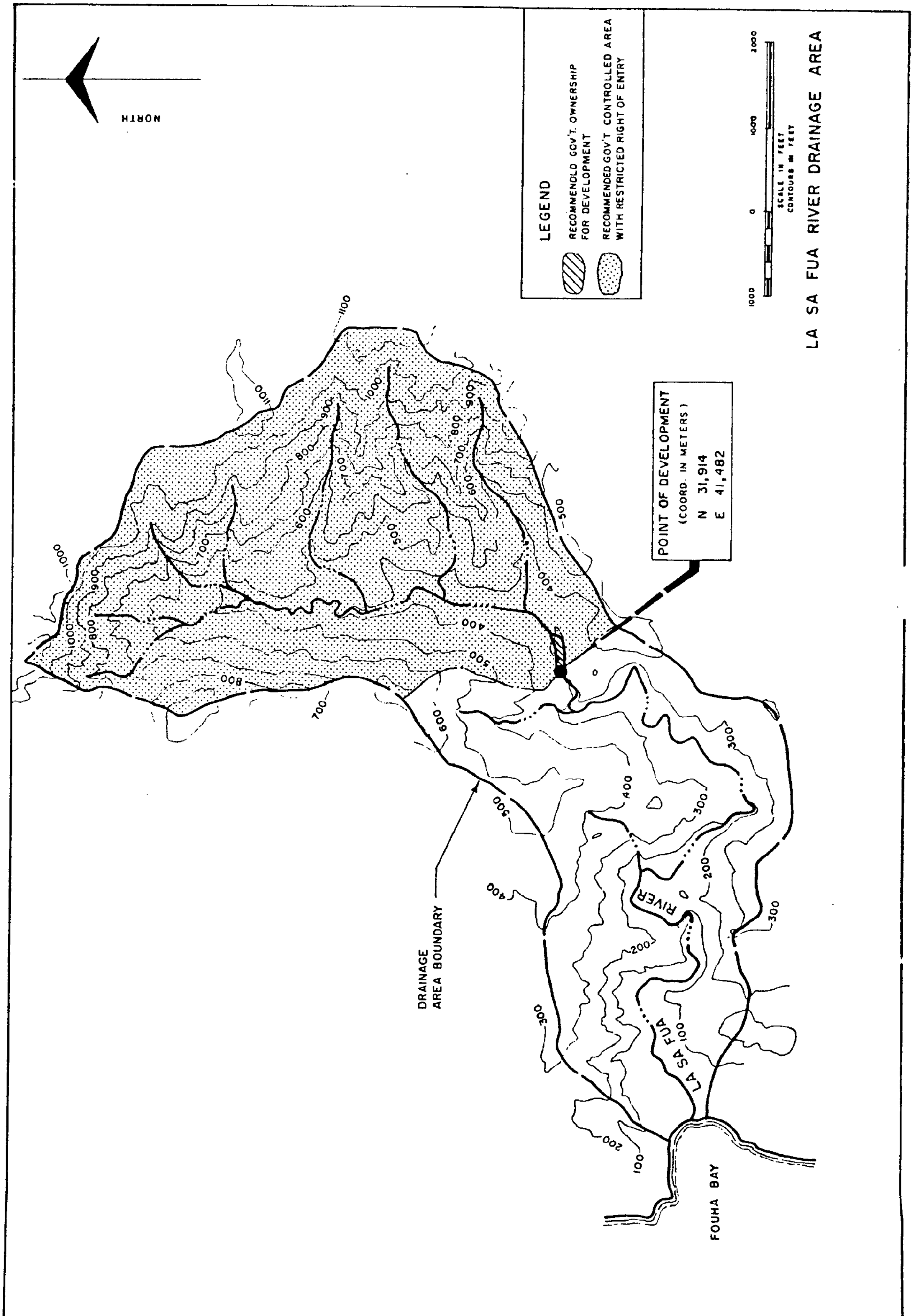




Geo-physical notes for La Sa Fua River basin.

General - flows in a rugged narrow gorge of eroded volcanic rock consisting mainly of lava flows. The River base flow is maintained by numerous small seeps and springs, the largest of which, the Alatgue Spring, discharges normally 40,000 gallons per day.

Point of discharge - Fouha Bay, southwestern coast of Guam.[35]



NORTH
LEGEND
RECOMMENDED GOV'T. OWNERSHIP FOR DEVELOPMENT
RECOMMENDED GOV'T CONTROLLED AREA WITH RESTRICTED RIGHT OF ENTRY
1000 0 1000 2000
SCALE IN FEET
CONTOURS IN FEET
LA SA FUA RIVER DRAINAGE AREA
POINT OF DEVELOPMENT
(COORD. IN METERS)
N 31,914
E 41,482
DRAINAGE AREA BOUNDARY
LA SA FUA
RIVER
FOUHA BAY

DURATION DISCHARGE CURVE

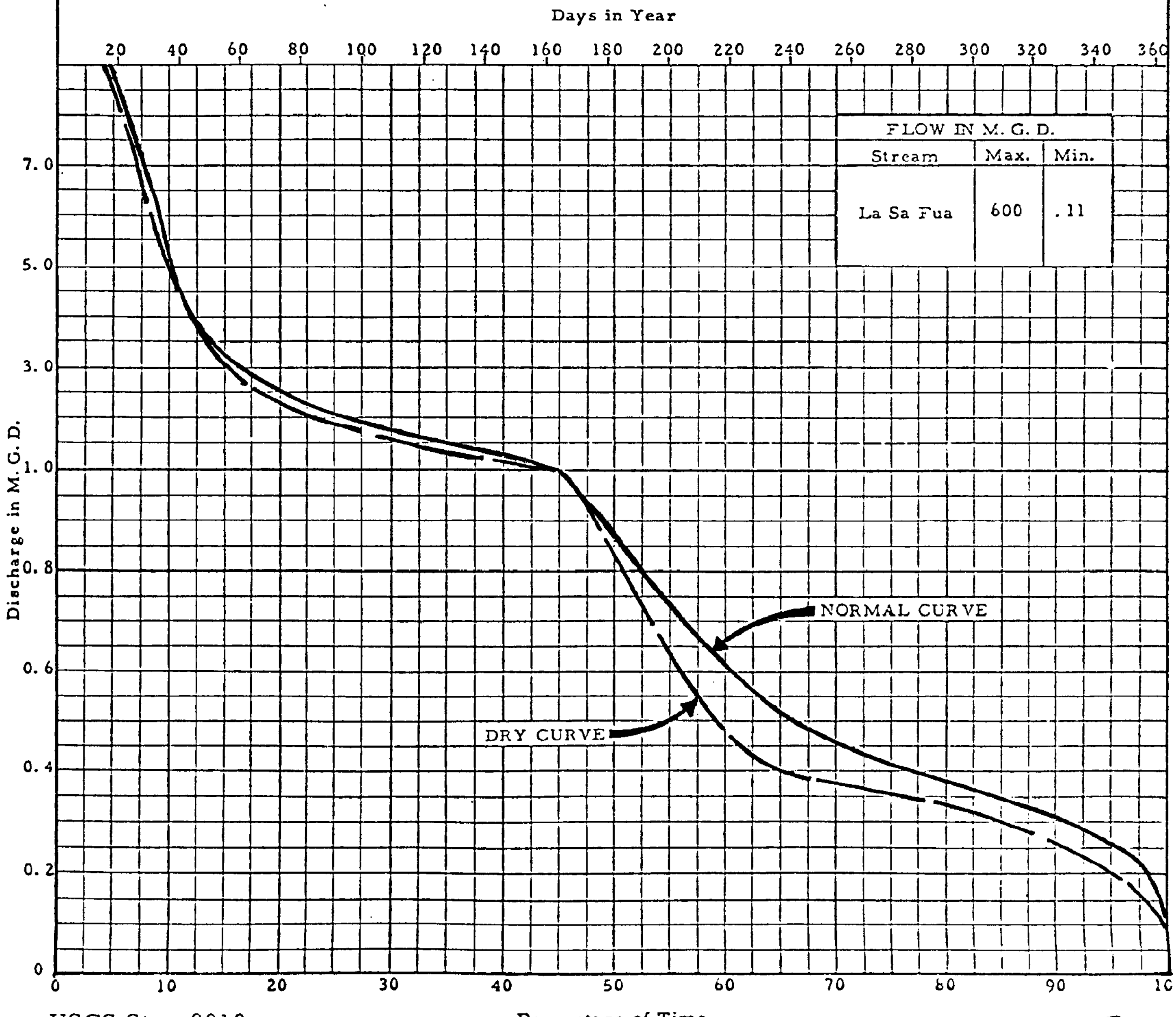
LA SA FUA RIVER NEAR UMATAC

Record - 7 Years
1952 - 1961

Discontinued July 7, 1961

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
2645 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	34	83	129	187	273	447	667	874	1214	1620	2054	2608	2645	2645
No. of days in Dry Yr.*	2	11	18	27	39	57	87	118	168	206	239	349	366	366
Percentage of time	0.6	3.0	4.9	7.4	10.7	15.6	23.8	32.2	45.9	56.3	65.3	95.4	100	100
No. of days in Av. Yr.	4.7	11.5	17.8	25.8	37.7	61.7	92.1	120.6	167.5	223.6	283.5	359.9	365.0	365.0
Percentage of time	1.3	3.1	4.9	7.1	10.3	16.9	25.2	33.0	45.9	61.2	77.7	98.6	100	100

*Fiscal Year 59-60



USGS Sta. 8010
Elevation 130'±

FIGURE

Measurements. The flow duration curves and data for the La Sa Fua are shown in Figure 4-25. These measurement records show that the flows vary from 600 mgd to .11 mgd for a period of record of 2,645 days from 1952 to 1961. The average flow recorded at guaging station #8096 is 2.57 mgd. One headwater location is targetting on the Army Corps of Engineers map, just downstream from the guaging station and .5 miles from the mouth of the river. Because the stream has sustained base flows in excess of .25 mgd for 95% of the time it has been recommended as a site to augment the Umatac treatment plant during the dry season.[36]

Power/head characteristics. Approximately 94% of the La Sa Fua drainage are is at an elevation in excess of 100 feet. The river basin lies in a steep gradient with the upper reaches of the stream originating at elevations of 900+ feet.

Since the river has relatively low average flows, it could not be developed for large hydro applications. Also, the development of the stream to augment the Umatac treatment plant as mentioned above would further diminish the hydro potential.

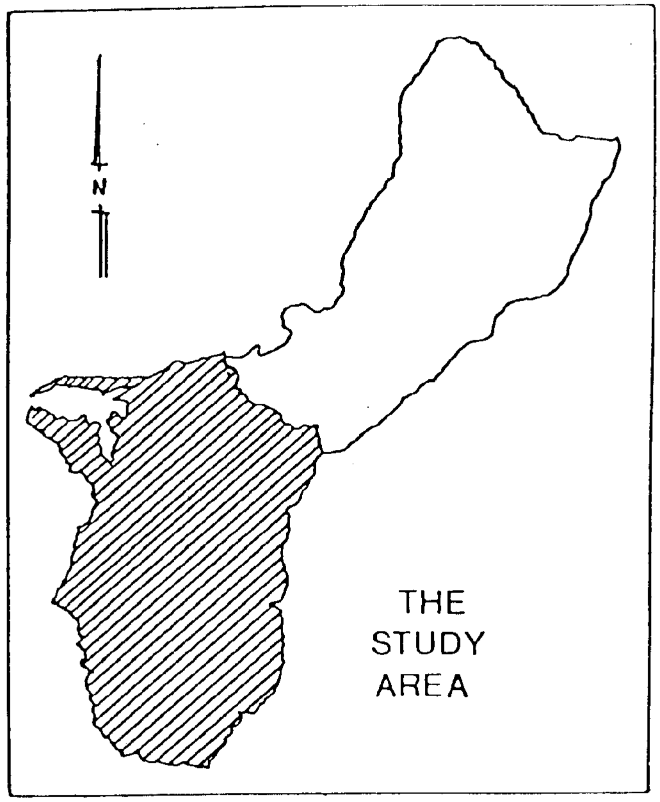
The stream does have a steep gradient, and falls from the prospective point of development at an elevation of over 300 feet to sea level in less than 2.5 miles. From the 200 foot contour a straight line to the intersection of the river and the 100 foot contour is less than .3 miles distant. This means that heads of 50 to 75 feet are available with a minimal penstock requirement, making this section particularly attractive for a small, 5 to 7 kW plant, provided a suitable impoundment area could be located.

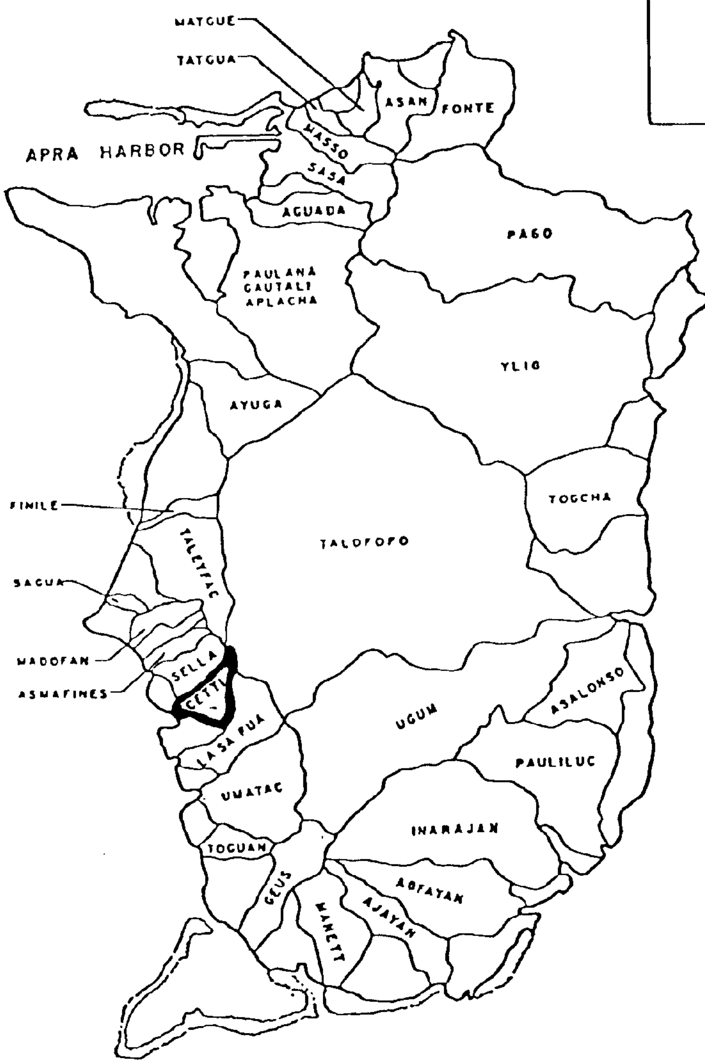
The last two major drainage areas are mentioned not because of their size but because they have sustained flows during low flow periods. For this reason they have been considered for domestic water sources. Also, they have stretches with steep enough gradients to allow enough natural head to support small scale hydro plants.

J. Cetti River

Drainage area = 1.8 sq mi

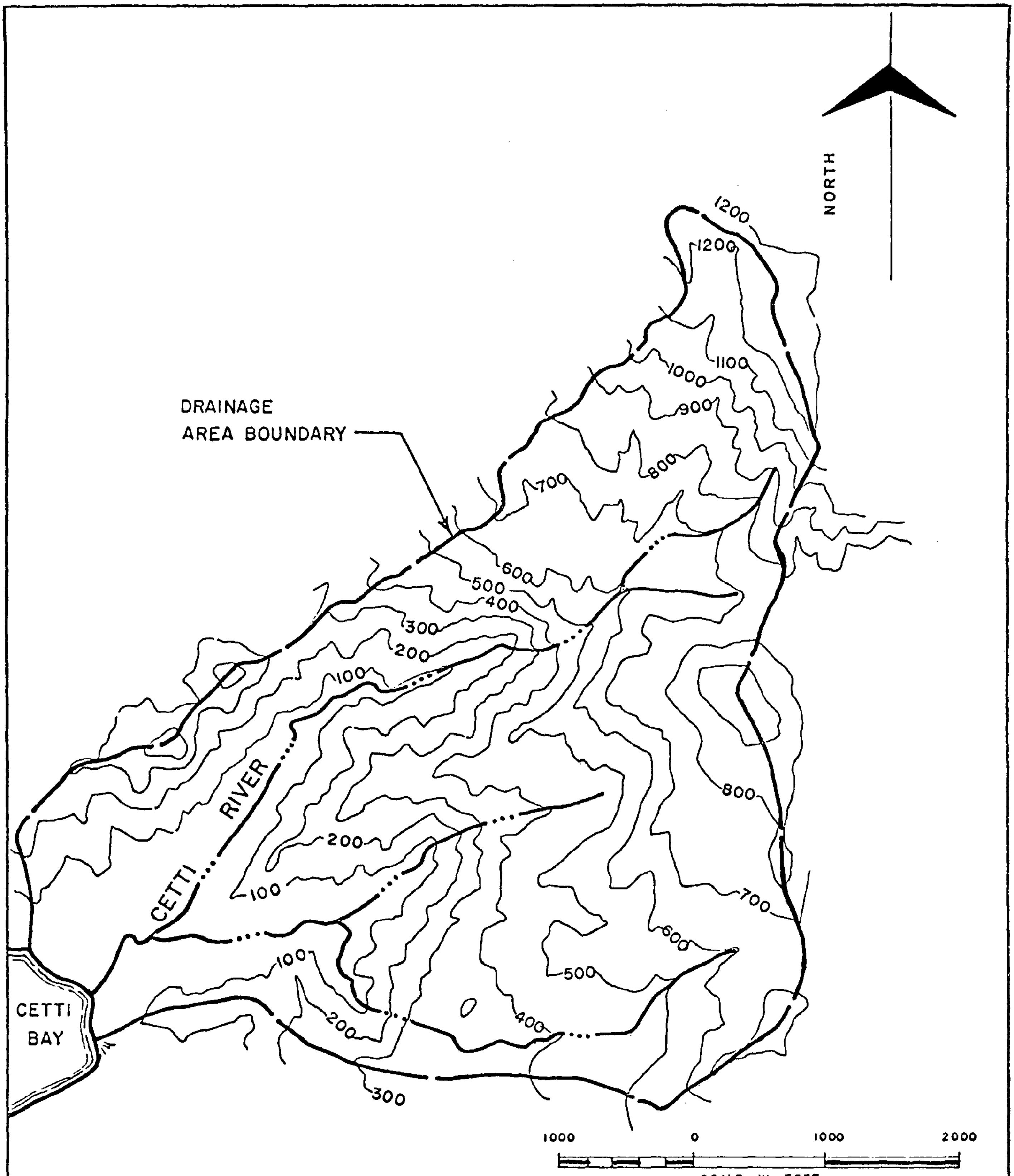
Located in the western section of the study area, the Cetti River drainage area lies immediately north of the La Sa Fua drainage area. It is a small drainage area composed of two main branches which intersect less than 1,000 feet upstream from the point of discharge, Cetti Bay.[37]





Geo-physical notes for Cetti River Basin

General - similar in topography and geologic features to those of its neighbor, the La Sa Fua drainage area.
Point of discharge - Cetti Bay, southwestern coast of Guam.[38]



CETTI RIVER DRAINAGE AREA

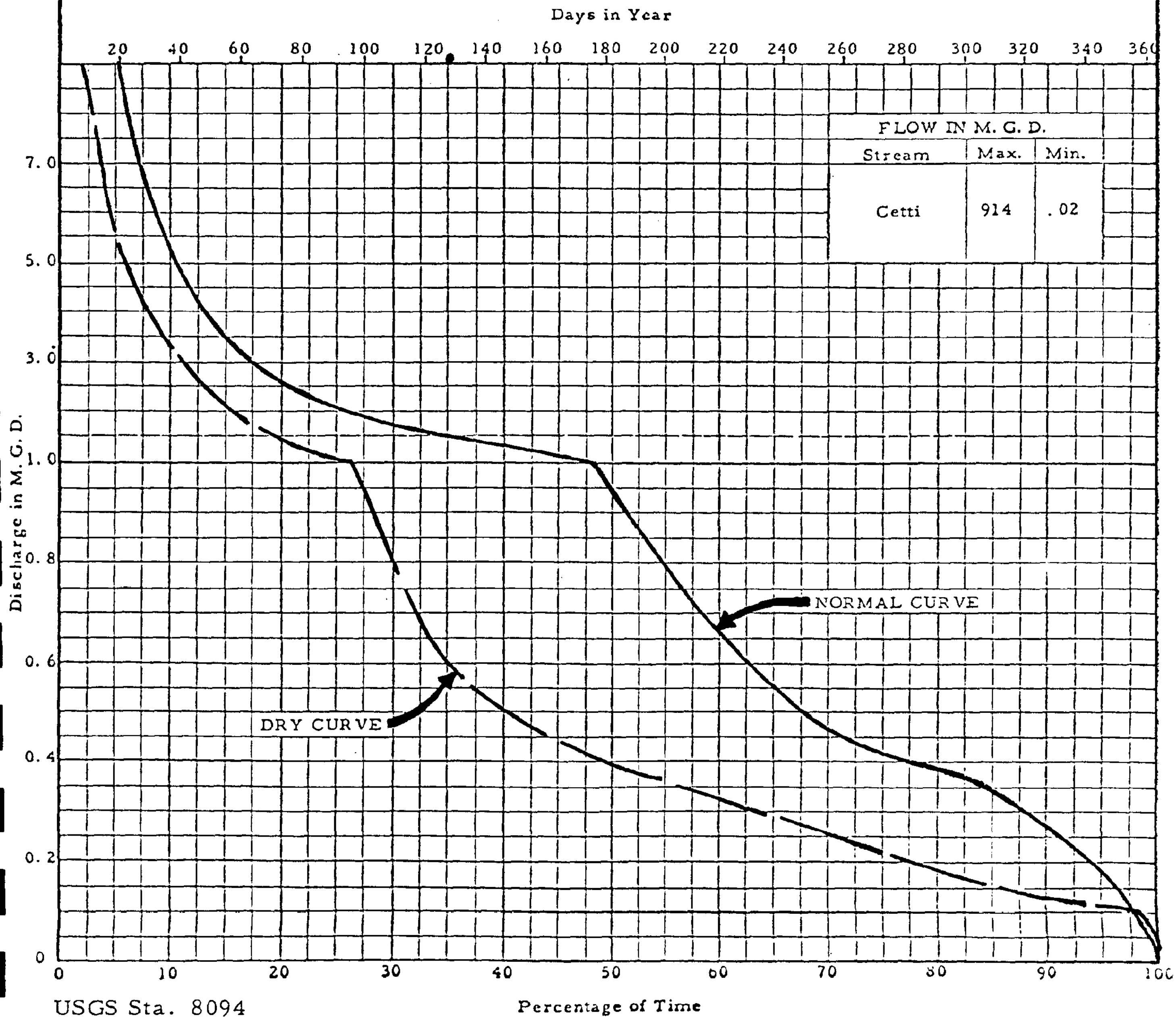
DURATION DISCHARGE CURVE

CETTI RIVER NEAR UMATAC

Record - 7 Years
1959 - 1967

Period of Record	Discharge Equal to or Exceeding - in M. G. D.													
2696 Days	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	48	88	141	207	281	485	695	909	1311	1705	2109	2538	2660	2696
No. of days in Dry Yr.*	4	7	8	14	19	42	55	72	96	129	181	287	362	365
Percentage of time	1.1	1.9	2.2	3.8	5.2	11.5	15.0	19.7	26.3	35.3	49.6	78.6	99.2	100
No. of days in Av. Yr.	6.5	11.9	19.1	28.0	38.0	65.7	94.1	123.1	177.5	230.9	285.5	343.6	360.1	365.0
Percentage of time	1.8	3.3	5.2	7.7	10.4	18.0	25.8	33.7	48.6	63.2	78.2	94.1	98.7	100

*Fiscal Year 65-66



USGS Sta. 8094
Elevation 10'±

FIGURE

Measurements. The flow duration curves and data for the Cetti area are shown in Figure 4-27. These measurement records show that the flows vary from 914 mgd to 0 for a period of record of 2,696 days from 1959 to 1964. The average flow recorded at guaging statin #8094 is 2.87 mgd. Ninety percent of the time the flow of this river is .26 mgd. There is no headwater location targetted by the U. S. Army Corps of Engineers.[39]

Power/head characteristics. Due to the low average streamflow, the Cetti River has very limited hydro potential. The north branch of the river occupies about half of the drainage area and consequently the flow is estimated to be approximately 1.4 mgd at its intersection with the south branch. This flow is coupled with heads in the order of 20 to 25 feet which could produce 4 to 5 kW of power, enough for a small farm application.

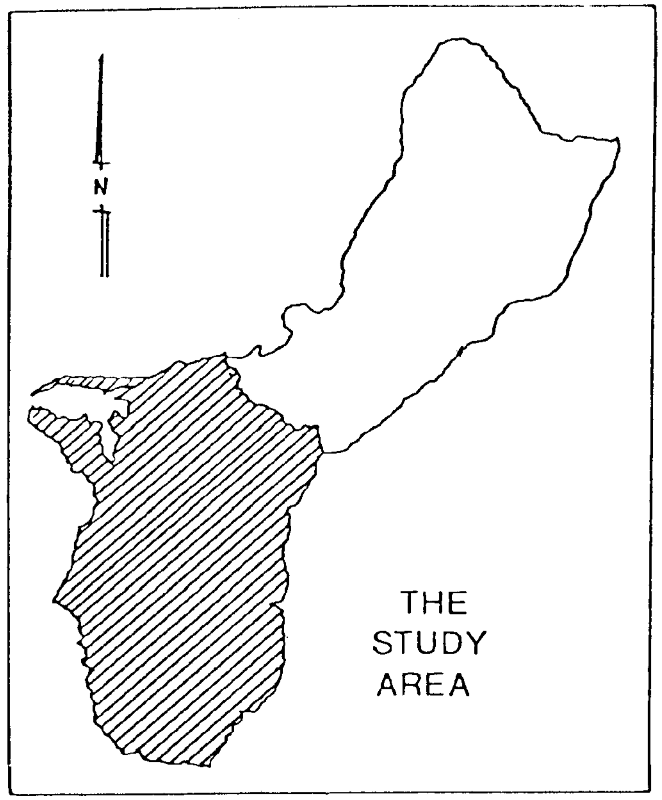
Unfortunately, the sections of maximum flow lie on the bottom, low gradient sections. In the upper reaches, the high gradient sections, the river falls from the 600 foot contour in the North branch to the 100 foot contour within 1,400 feet. In this section low flows could combine with these high heads using impulse wheels of Pelton turbines to generate between 4 to 6 kW provided a suitable impoundment area could be located.

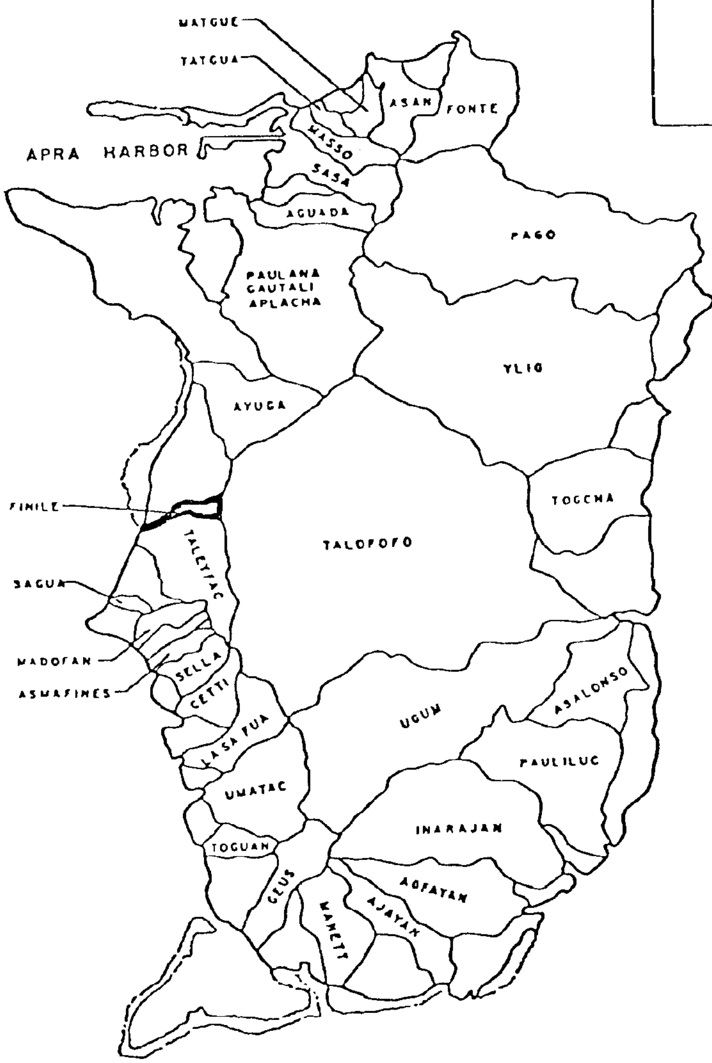
Because of the low generation potential, the Cetti is still a low priority area for development. Contributing to the negative argument is the fact that the Cetti River lies far from centers of population and the storage capabilities are small.

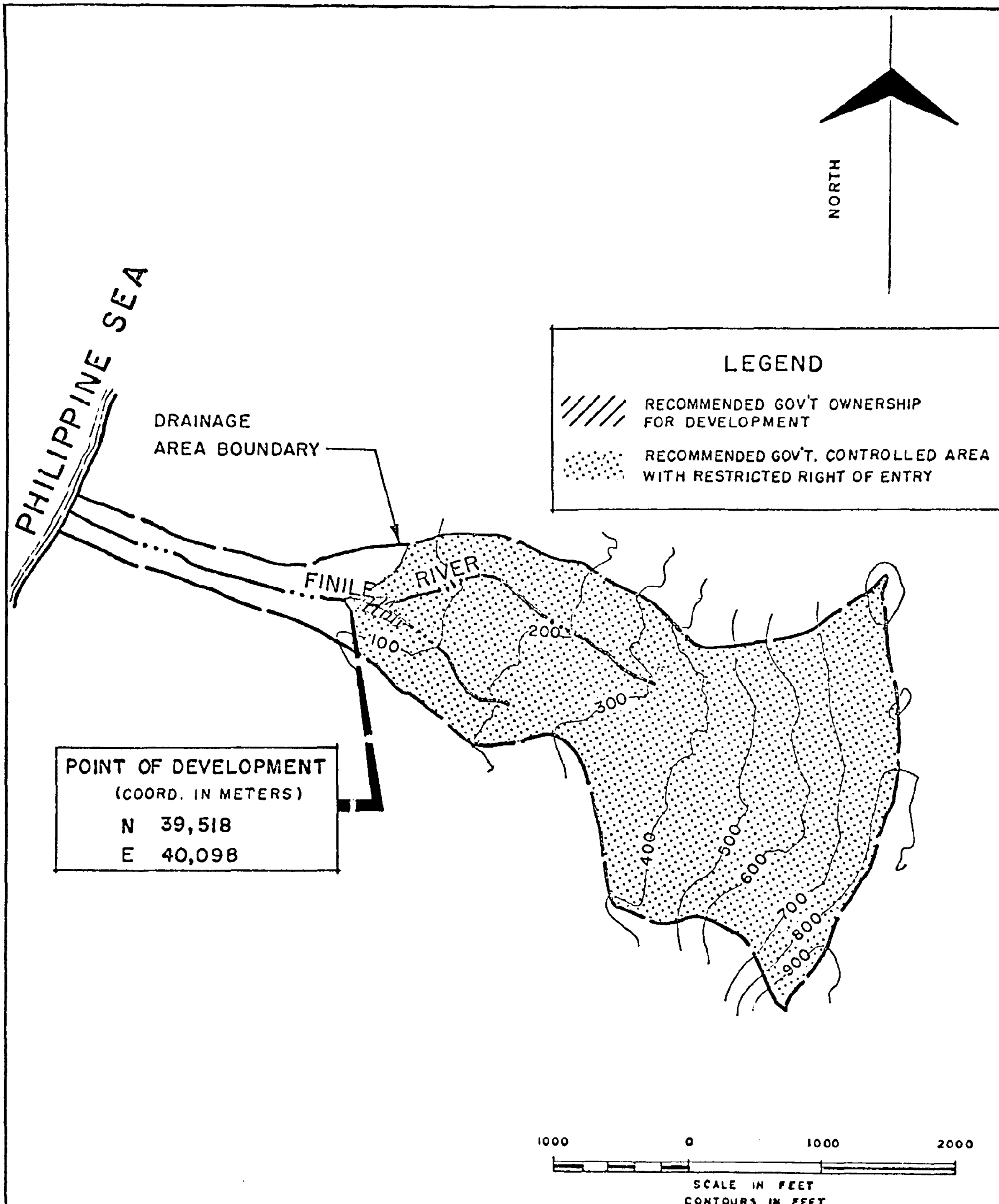
K. Finile Stream

Drainage area = .3 sq mi

Located in the western section of the study area, the Finile River drainage area lies just south of the village of Agat. This small drainage basin is mentioned because its gradient it is quite steep and is near a point of use.[40]







FINILE RIVER DRAINAGE AREA

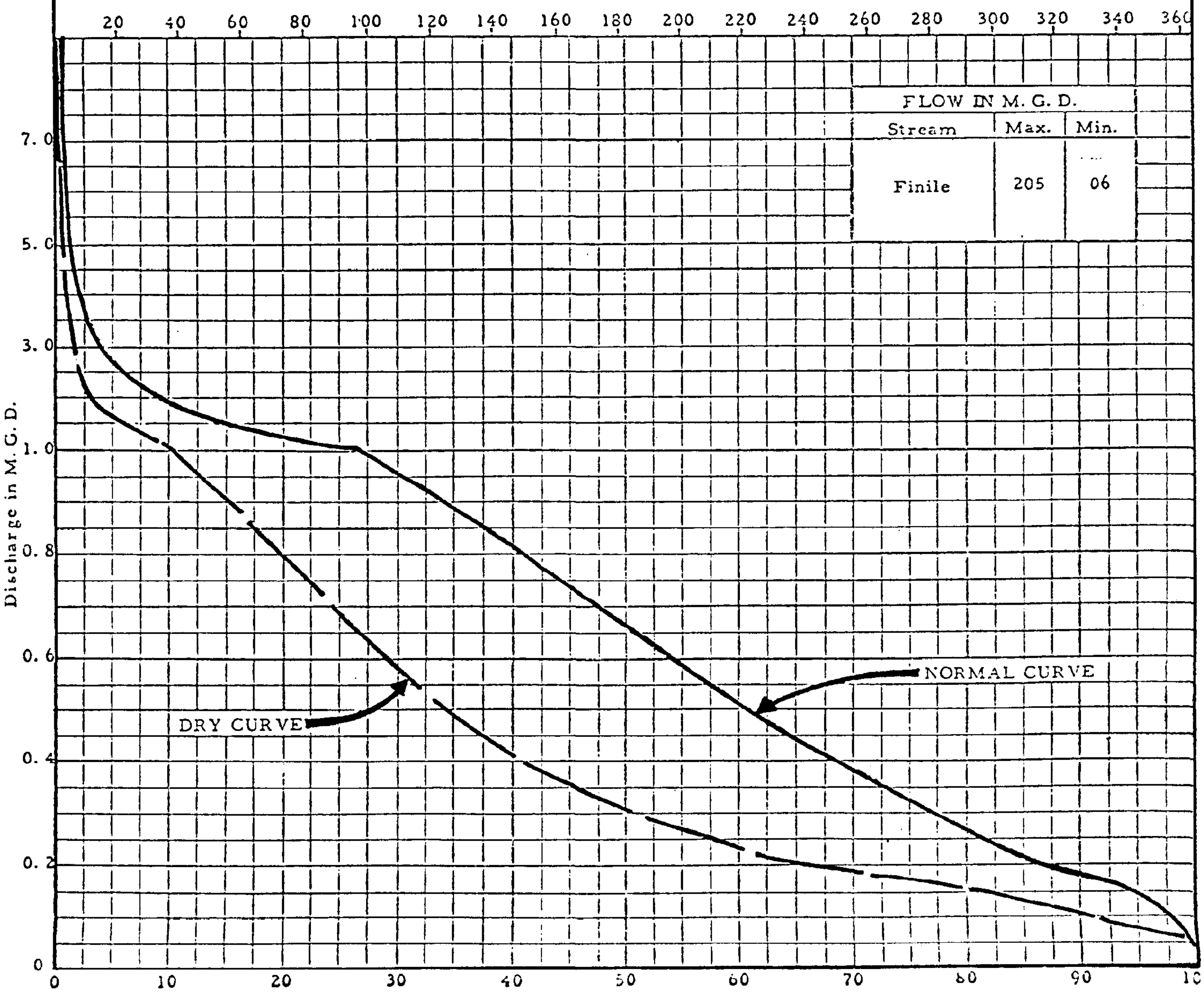
DURATION DISCHARGE CURVE

FINILE STREAM AT AGAT

Record - 7 Years
1959 - 1967

Period of Record 2647 Days	Discharge Equal to or Exceeding - in M. G. D.													
	25	15	10	7	5	3	2	1.5	1.0	0.6	0.4	0.2	0.1	0.0
(Partial Years Included)	1	2	9	24	41	118	228	364	711	1428	1831	2296	2595	2647
No. of days in Dry Yr.*	0	0	0	1	1	6	11	20	38	106	149	245	336	365
Percentage of time	0	0	0	0.3	0.3	1.6	3.0	5.5	10.4	29.0	40.8	67.1	92.0	100
No. of days in Av. Yr.	0.1	0.3	1.2	3.3	5.7	16.3	31.4	50.2	98.0	196.9	252.4	316.6	357.8	365.0
Percentage of time	0.0	0.1	0.3	0.9	1.5	4.5	8.6	13.7	26.9	53.9	69.2	86.7	98.0	100

*Fiscal Year 65-66



Percentage of Time

USGS Sta. 8083
Elevation 20'±

FIGURE

Measurements. The average flow of the Finile creek is .92 mgd. Ninety percent of the time the flow is .13 mgd. This is measured at gauging station #8083 (fig. 4-29). The record for this station shows that the flows vary from 205 mgd to .06 mgd for a period of record of 2,647 days from 1959 to 1967. Based on this record, a flow of .2 mgd can be expected 65% of the time, even during drought years such as 1965 to 1966.[41]

Power/head characteristics. Like the Cetti, the Finile has low flow and consequently low hydro power potential. Also, like the Cetti, the Finile is a relatively sure source of water and in a normal year could be expected to deliver .3 mgd roughly 75% of the time. This means that a small installation - say, 2 kW, could be developed and generate power most of the year. Heads from 25 to 40 feet could be developed just upstream from the guaging station as the station elevation is about 20 feet and the 100 foot contour is within 1,000 feet. On the negative side, the Finile basin has been described in technical surface water studies as being too steep for practical ponding or storing stream water.

L. Other Drainage Areas and Springs

Eleven drainage areas have been thoroughly described above. These were described first because they are all the major candidates for development of surface water for domestic use. Consequently, these water bodies have the most complete data base, and have been studied for potential impoundment areas and water sales. Recommendations of land mass purchase necessary to development have been made and are shown as the shaded areas in the drainage area maps. As a result, they are considered to be the most developable basins.

There are many other spots on Guam's rivers which could support a small farm or home hydro application in sizes up to 10 kW. Small hydro installation are futher addressed in Chapter II.C.5, Hydro Strategies, under "Small Scale Applications".

M. Springs

In the study area there are numerous springs and seeps which help maintain the base flow of the various streams. Many have been addressed within the discussion of the drainage area of which they are a part. The more productive springs such as the Alamagosa, Bona, Alatgue, Piga, Siligin, and Santa Rita are currently being tapped for military or local domestic water, and have been already addressed in this report. There are also two other springs, Asan and Agana Springs, that are located within the study area.

Asan Springs provides domestic water for the village of Asan at the average rate of about .3 mgd. The overall average production of this spring is .5 mgd at an elevation of 140 feet. The flow of this spring varies seasonally from a low of .1 mgd to a wet weather high of 1 mgd. Although approximately

7 to 10 kW of power could be generated from this source if a penstock were run down to sea level, it is unlikely that it would be developed as the Government of Guam is already using the spring water.

The Agana Springs are located on the edge of the Agana swamp and have been a source of domestic water since before World War II. The springs have a wide seasonal fluctuation in flow and lacks any developable head required for hydro development, but has yielded an average of 1.5 mgd as a domestic water source.

NOTES FOR CHAPTER IV

1. Austin, Smith & Associates, Inc., A Report Covering the Surface Water Survey of the Island of Guam Public Utility Agency of Guam Report, Agana, Guam June 1968, pp. 11-12

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Chapter V

V. EXISTING WATER FACILITIES

It has already been mentioned that the amount of hydroelectric energy that may be generated depends on the quantity of water available, the vertical distance the water falls, and the ability of the power plant to use the flow. Consequently, this study initially addressed the questions: "How much head is potentially available?" and "How much water is available in a source?" The next step is to discuss the power plant itself and its ability to use Guam's available water resources.

Hydraulic plants may be classified by the degree of water-flow regulation they can exert. A run-of-the-river plant has no control over the flow of the river, and uses it just as it comes. The other extreme is a hydraulic plant with water storage that allows it to compensate for high and low flow periods by accumulating and discharging the stream water. In either case, there are basic component requirements that must be met for electrical power to be generated. These are basic civil works fundamental to any hydro plant discussed in detail in Chapter II, Hydro Strategies, and are as follows:[1]

1. A dam. Even in a run-of-river application a small dam must be constructed to maintain the upstream water level and divert the water to the

powerhouse.[2]

2. A spillway. This is an important requirement on Guam where torrential rains create flow levels many magnitudes above the average flow. The spillway allows the floods or excess flows to pass around or safely over the dam.[3]

3. Outlet works. This is the part of the dam that passes water to the downstream side from the reservoir and includes: an entrance channel; trashracks; intake structure; waterway; water-control system; bypass valves; access shafts, and bridges or tunnels necessary for operation and maintenance.[4]

4. Powerhouse. This contains the hydraulic turbine/generator and a foundation for the powerhouse.[5]

5. Bypass works. These divert the water directly downstream in case the turbine is not functioning.[6]

6. A switchyard and transformer. This allows the generator to be connected to the transmission line.[7]

7. Environmental structures, such as fish ladders.[8]

8. Temporary civil structures. Usually if a dam is constructed, a temporary or coffer dam is built to divert the river during construction.[9]

In terms of cost payback, it makes good economic sense to utilize any existing structure that could provide the function of, or defray the cost of, those basic civil components of the hydro installation listed above. Since there is no existing hydro installation that may be renovated or reactivated, the next target to consider is Guam's existing water facilities. Consequently, this section of the study will discuss the potential of using any existing water facility, particularly existing impoundment areas, as a starting point for a hydraulic plant.

A. IMPOUNDMENT AREAS

There are four major impoundment areas in the study area. These are the Asan Springs Storage Basin, the Santa Rita Springs Sorage Basins, the Geus River Dam, and the Fena Reservoir.

1. Asan Springs

Originally constructed by the U. S. Navy in 1929, the Asan Springs Storage Basin initially included an uncovered storage basin, a perforated conduit with gravity discharge penetrating into the hillside, and an overflow spillway. The basin itself has a storage capacity of about 30,000 gallons resting in two storage compartments, ten feet deep. Since its installation, additions have been made, including a concrete roof covering two vertical turbine booster pumps designed to operate one at a time and to pump against the head supplied by the Piti Reservoir.[10]

Hydro power potential. The estimated discharge of this Asan facility is 120 gallons per minute or .17 mgd. As this figure indicates, only minimal theoretical power potential exists at this source, about 170 watts, and certainly not enough to economically justify diverting this source of water from the Piti Reservoir.[11]

2. Santa Rita Springs

Also constructed by the U. S. Navy in 1929, the Santa Rita Springs facility is similar in construction to the Asan Springs facility. It has two storage basins with a combined capacity of 105,000 gallons. Water from the storage basins flows by gravity to its point of use, the old Agat and Hyundai subdivision area.[12]

Hydro power potential. The estimated discharge of the Santa Rita Springs is 50 gpm or .07 mgd. The springs are located at the foot of a hill allowing little potential to develop head immediately at the site. Like the Asan Springs facility, the Santa Rita Springs and its impoundment area are used to supply domestic water. The Asan facility uses the available head at the site on the suction side of the pump which delivers the water. Any available head at the Santa Rita facility is used to provide the gravity flow to the domestic water point of use.

The minimal hydro potential at the Santa Rita facility is not economically developable.

3. <u>Geus Dam</u>

Approximately 100,000 gallons are impounded behind the Geus Dam, and old concrete dam and diversion structure. The stored water is sand filtered and delivered to the transmission main and then to the Pigua Booster Pump Station. The dam is a small structure, less than ten feet high, and is considered to be a marginally reliable source of water due to dry periods.[13]

<u>Hydro power potential</u>. The estimated capacity of the Geus River Dam as a water supply is 70 gpm or .1 mgd. As in the Asan and Santa Rita Springs cases, the combination of low flow, low head potential at the immediate site, and existing domestic water distribution systems which use available head, make this site economically undevelopable as a hydro plant.

4. Fena Reservoir

Constructed in 1951 by the U. S. Navy for military use, the Fena Reservoir is located in the Talofofo River Drainage Area, and more specifically, in the Naval Magazine. Fena Dam is about 85 feet high, 1,050 feet in length and is stocked from a six-square-mile watershed giving it a capacity of approximately 2.3 billon gallons. The Fena Dam has been addressed as a potential hydro site in Chapter III D under the Talofofo River Basin. That section includes a flow duration curve based on data accumulated at guaging station #8490, which measures the water discharged over the Fena Dam spillway That section also shows that the Fena Dam could be augmented with a 135 kW power plant that would produce about 327,000 kWh in a normal year. At $0.10 per killowatt, this amount of energy would cost $32,700.00 per year. If that amount was paid as a yearly payment to amortize a 20 year loan at equal annual payments at 10% interest, it would support a loan of $278,393.50 which would cover the power plant installation cost (provided there was no excessive cost in dam modification). As mentioned earlier, the power generated could be used at the dam to help power the four 3,500 gpm, 300 horsepower pumps which are presently used at the reservoir to deliver the water from the dam to the Fena water treatment plant, three miles away.[14]

The Fena reservoir has existing access roads which could accomodate equipment necessary for construction and refit. It also has existing electrical hookups on site which facilitate generation.

There are other impoundment areas and clearwells in the study area, such as the Ylig, but none with storage capacities great enough to be useful for hydro power generation, and none as large as those discussed above.

B. WATER DISTRIBUTION FACILITIES

Once the domestic water supply has been treated it is distributed by a system of the following components:

1. Booster pumps.
2. Pipelines.
3. Control valves.
4. Hydrants.
5. Storage reservoirs.
6. Service connections.
7. Meters.

This system provides the water at a usable pressure for home and commercial use. This pressure range is normally between 40 to 80 psi. In many cases the water must be supplied to higher elevations to provide adequate service.

Guam's water distribution system was not designed and built in one phase. It has evolved since pre-war periods, adjusting to new water demands. When originally designed, energy was much cheaper and no real design constraint. As a result, investigation into the system design reveals energy inefficiencies that are not cost effectively changed. For instance, water is pumped from sources to high elevation storage. Then the water flows from these high elevation storage points, by gravity, to use points, frequently miles away, at much lower elevations. The high head in these situations effect pressure increases, that are alleviated by pressure release valves.

An example of this scenario is the case of the Barrigada Reservoir which supplies part of the Tumon Area. On San Vitorius Road about 800 feet from Marine Drive, the pressure release valves are located. They bleed the excess pressure caused by the difference in elevation of Barrigada Reservoir and the beach road.

In the aggregate, these inefficiencies sum up substantially, but on a case by case basis are uneconomical to remedy. It is unlikely that the entire water system will be redesigned in the near future, and there is little administrative emphasis on correcting minor energy losses compared to the numerous water leaks in the system.

NOTES FOR CHAPTER V

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Chapter VI

VI. FURTHER ECONOMIC CONSIDERATIONS

A. WATER SALES

The study area, as a result of its geophysical structure and population, is not self-sufficient in terms of water supply and demand. It uses more water than it presently produces, and consequently was the topic of study to see what surface water systems could be developed to provide for the present and future water needs.

At the time of this study, Public Utility Agency of Guam customers spend $1.17 per thousand gallons of domestic water. For a home, the total bill is usually under $15.00 a month and represents no serious financial burden.

For a farmer who pays to irrigate, it is a different matter, and his bill is many times the average home bill. For this reason, a hydro installation may provide more than one benefit. In addition to providing power, the system may easily be designed to provide all of the farm water needs. The yearly water bill may then be applied toward the yearly hydro payments as a further cost hedge.

On a large scale, the Public Utility Agency of Guam presently pays about $0.11 per 1,000 gallons to companies that develop large water sources refered to in this study. This figure follows a general inflation curve to accomodate for increase in cost due to maintenance and operations and provides the incentive to develop new water sources as demand dictates.

To indicate the impact of this incentive, contrast the water sales to hydroelectric development. First, consider the case of the developer who owns a water-shed producing 1 mgd 90% of the time. The point of development chosen lies at 100 feet elevation in an average gradient section. At $0.11 per 1,000 gallons, the Public Utility Agency of Guam will pay the developer $36,135.00 the first year. If this amount is used as an equal annual payment in a 20 year loan at 10% interest, the developer can borrow $307,637.63 to develop the source.

Now, consider the same site but developed to produce hydroelectric power. Assume his plant uses a steady 1 mgd. This flow of water is available 90% of the time, and his plant develops 20 feet of head at a plant efficiency of 80%. His plant would produce a relatively constant 2.8 kW of power for a yearly production of 24,589 kWh. To buy this power at $0.10 per killowatt would cost him $2,459.00 the first year. Applying that as a payment in the above loan would allow the developer to borrow $44,372.14 or a difference of $263,265.49. Furthermore, the developer does not have to pay for water treatment and pumping costs.

This is the reason why existing sites that appear to be good hydro prospects are not cost effective to change if thay are being used as a source of domestic water.

Similarly, proposed sites at high elevations gain more by using the existing head potential to deliver the water than by generating electricity, particularly if the electricity is to be used to deliver the water.

B. COST OF ENERGY

All of the calculations in this study are based on a flat cost of electricity at ten cents per killowatt hour. It is obviously inaccurate to insert this cost in a loan amortization of 20 to 30 years at no projected increase, but since no one knows what will happen to the cost of electricity on Guam, there is no alternative.

Historically, the unit cost of electricity doubled between 1978 and 1980. If this rate of increase is used as a basis for a life cycle cost analysis, the equation quickly becomes distorted, particularly in view of the fact that this cost is based on a fossil fuel generation plant. Alternatives such as the Ocean Thermal Energy Conversion (OTEC) generation scheme project unit costs of electricity of between $0.15 and $0.20.

Anyone viewing a graph depicting the local rise of electrical cost over the past five years (1975 to 1980) would have to agree that the curve cannot realistically continue to steepen, but that it must level off at some point. Unfortunately, not everyone can agree on this point.

The Guam Power Authority projects an increase of around 10% to 15% per year. Obviously, this has not proven to be historically accurate. One can safely assume that over the near term, say the next five years, the unit cost of electricity will increase between 10 to 20% per year.

This means that any potential hydro installation that is within 10 to 15% of being cost effective based on an electrical unit cost of $0.10 will surely be cost effective in the long term as the rising local cost of electricity steadily enhances alternate energy prospects.

C. TAX INCENTIVES

The Crude Oil Windfall Profits Tax Act (COWPTA) of 1980 enacted other hydro incentives. One incentive is a Business Energy Investment Credits provision. This allows credits of 11% for investments in projects at existing dams up to 25 MW in size. Property that is eligible for the tax credit includes all hydroelectric related equipment up to the transmission stage. Included in this are generators, turbines, powerhouses, and the rehabilitation of dam structures, plus fish ladders or passageways. The credit is available through the end of 1985, with an extension through the end of 1988 in the case of a lisence application docketed by the FERC before 1986. This credit augments the existing 10% tax credit for alternate energy systems.[1]

The COWPTA also makes fish passageways eligible for the 10% tax credit, and increases the use of the tax-exempt industrial development bond as a financial mechanism for hydroelectric projects. This tax exemption now extends to those industrial development bonds where proceeds are used to finance small-scale projects located at existing dams and natural water features currently owned by the local government.[2]

D. LONG RANGE IMPACT OF HYDROELECTRICAL DEVELOPMENT

As a present alternative to fossil fuels, hydro electric plants are more cost effective than OTEC, solar, wind or biomass. Additionally, this technology has been proven for centuries as a reliable, low maintanence form of generation, with plant lifetimes of up to 50 years and longer.

Corresponding costs of generated electricity are, consequently, almost static and provide the plant owner with a real hedge against runaway inflation compared to commercial utility costs that have doubled in the past two years (1978 to 1980).

NOTES FOR CHAPTER VI

1. IOAHO National Engineering Laboratory, Small Hydro Bulletin U. S. Department of Energy Report, Vol. 2, No. 4 December 1980, p. 4

2. Ibid.

Chapter VII

VII. CONCLUSIONS AND RECOMMENDATIONS

1. Hydroelectric generation is presently cost effective at the best local sites. Those sites that are close but not presently cost effective will become so within the next five years.

2. Hydroelectric sites are attractive long-term investments. Relative to the future cost benefits of a hydro installation, history has proven this system repeatedly. The author cannot predict the exact future cost of energy, however, based on the current state of alternate energy research and development in conjunction with the characteristic administrative and industrial lags, energy costs will probably rise in the next five years to a unit cost of between $0.15 to $0.20 per killowatt. At this point several alternate system and cogeneration possibilities could conceivably stabilize the unit cost. There are always possibilities of technical breakthroughs as happened at the turn of the 20th Century with petroleum development which provided a brief respite from escalating energy costs, but again hydroelectric projects were proven economical even during this period and continue to develop electricity.

3. There is an acute need for local information generation and dissemination designed to promote the

development of small scale hydro systems in the range of 2 to 10 kW, as a followup on this and other studies.

4. There is a need for establishing recording guaging stations at potential hydro sites, in order to accumulate accurate design data. The lack of specific data restricts the number of sites that may be evaluated. For instance, one hydro scenario of very low-head hydrogeneration could not be accurately addressed in this report. To develop any sizable power using very low heads, large flow volumes are necessary. On Guam, the downstream stretch of the Talafofo River, beyond its confluence with the Ugum River, is such a location. This section was investigated assuming an average combined flow of 50 mgd, and was determined not cost effective at current electrical rates ($0.10/kWh). Should the cost of electricity increase over, say, 30%, then this site may be economically developed.

Without accurately guaged data, however, it is impossible to make any precise calculation, particularly when the downstream reaches of the Talafofo flow over permeable alluvial soil which affects the ultimate discharge.

6. There is a need for the development of information on related systems, specifically, hydraulic rams for pumping.

7. There is much that should be done to insure the licensing process and other legal and environmental problems

are minimized for the prospective hydro installer. Federal efforts are headed in that direction and the Guam local government should definitely take a similar stance. As mentioned in Chapter I, Legal Issues, the Federal Energy Regulatory Commission (FERC) has freed projects with a capacity of less than 5 MW that use existing dams or natural water features from the Federal Power Act licensing requirements. FERC was given the authority to exempt small hydroelectric projects from licensing requirements by the Energy Security Act of 1980. This legislation grants exemptions which free developers from annual fees, inspections, and the threat of Federal takeover. Furthermore, exemption applications are automatically granted if FERC fails to act on them within 120 days.[1]

NOTES FOR CHAPTER VII

1. IOAHO National Engineering Laboratory, Small Hydro Bulletin U. S. Department of Energy Report, Vol. 2, No. 4 December, 1980 p. 4

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